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The role of scaffolding in the instructional design of online, self-directed, inquiry-based learning environments: Student engagement and learning approaches

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Abstract

One of the profound educational challenges in the modern world where technology is all pervasive is for educators to harness the complex array of available tools in the quest to provide learning environments that facilitate the learning of students with diverse backgrounds and learning preferences. Engagement with this challenge has the potential to lead to the development and provision of programs that allow a more diverse student population to access these resources and become independent learners. However, the methods for the successful implementation of these technologies are still problematic in curriculum areas such as science education. This suggests that determining the features of such programs that are reflective of individual student needs requires careful deliberation and calibration. In this context, it is considered that the quality of differentiated support, referred to as scaffolding, is paramount in the design and structure of programs offered to students in an online environment.

This study strives to determine how to empower students as online learners and the role of scaffolded learning modules to support student engagement in their inquiry process has been investigated in the context of self-directed online environments. A powerful pedagogical scaffolding strategy, predict, observe and explain (POE) (White et al., 1992), originating from the paradigm of constructivism, has been adopted to formulate an extended predict, observe, explain and evaluate (POEE) pedagogical framework by introducing an additional Evaluate (E) phase. This noble scaffolding framework has been employed as the platform for the development of two learning modules that are used in this study to guide students in the process of learning abstract science concepts.

A mixed method research study has been applied to examine students' engagement and learning approaches within the scaffolded learning environment. This has been transacted through interviews, observations, video recordings and student written responses to provide a clear, multifaceted picture of students' independent interactions with the learning modules.

Findings from this study support the strategic value of an evaluate (E) phase, as an extension of the widely used predict, observe and explain (POE) scaffolding framework, in new learning contexts notably in self-directed online learning. In particular, the study exposed the considerable influence of strong instructional supports, strategic integration of multiple external representations, and question prompts embedded in the POEE scaffolded learning modules on students' ability to engage effectively with independent study. It is significant that learners with prior knowledge and experience

benefitted most in this self-directed environment in terms of their level of engagement and the deeper learning approaches they adopted; conversely the lack of prior knowledge and relevant experiences for some learners jeopardized their opportunity to gain deeper science conceptual understandings. This implies the need for more personalized learning settings for novice learners.

This study concludes that despite the inherent limitations manifest in the online context, scaffolded learning modules can provide a proximal learning environment for inquiry-based online learning. The findings of this study contribute to the growing body of evidence demonstrating that the strategically designed implementation of inquiry-based online learning holds promise for the creation of a successful learning environment to meet the ever-changing demand for online educational reform.

Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

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Publications during candidature

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online learning, self-directed inquiry learning, scaffolding, instructional design, science education

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Chapter 1
Introduction

One of the profound educational challenges in the modern world where technology is all pervasive is for educators to harness the complex array of tools on offer in the quest to provide learning environments that facilitate the learning of students with diverse backgrounds and learning preferences. Engagement with this challenge has the potential to lead to the development and provision of programs that allow a more diverse student population to access these resources and become independent learners. This suggests that determining the features of such programs that are reflective of student needs requires careful deliberation and calibration. In this context, it is considered that the quality of differentiated support, referred to as scaffolding, is paramount in the design and structure of programs offered to students in an online environment.

In this study, which strives to determine how to empower students as online learners, the role of scaffolded learning modules to support inquiry learning has been investigated in the context of the self-directed online environment. A powerful pedagogical scaffolding strategy, *predict*, *observe* and *explain* (POE) (White et al., 1992), originating from the paradigm of constructivism, has been adopted to formulate an extended *predict, observe, explain and evaluate* (POEE) pedagogical framework. This scaffolding framework has been employed as the platform for the development of two learning modules that are used in this study to guide students in the process of learning abstract science concepts.

Several key aspects for the development of online learning modules have been considered. First, the justification for the scaffolding strategies used in this study, most significantly the POEE model, multiple external representations, instructional guidance, and inquiry questions are considered. Second, it explores students' behavioural, cognitive, and attitudinal engagement with these scaffolded learning modules. Finally, students' learning approaches are investigated within the context of this study. Overall, this study aims to provide a "blueprint" for a scaffolding framework consistent with the emerging needs of online course development for inquiry learning. A qualitative research study methodology has been applied to examine students' engagement and learning approaches within the scaffolded learning environment. This has been transacted through interviews, observations and video recordings to provide a clear, multifaceted picture of students' independent interactions with the learning modules.

In this chapter, the major themes underpinning this study are introduced. The nature of the research problem and the context of the study proposed, and the three research questions that have guided the research study are presented. In addition, a number of issues pertaining to the background to the study are broached. These are relevant to the design and structuring of the study including the motivation for its design and implementation.

1.1 Motivation and background

Currently, the modes for delivering educational instruction impacting on learning environments are changing due to rapid technological advances. These monumental changes allow for more flexible learning in the online context (Ally, 2004; Dillahunt et al., 2014). Indeed, the online environment is becoming established as one of the most powerful means for bridging the gaps of time and space, between learners and teachers and between the delivery and reception of content (Cole, 2000; Murphy, 2013). Unsurprisingly, learning from a distance (distance education), or at least in part online (blended learning), alongside face-to-face learning, is becoming relatively commonplace in today's technologically advanced world. While there is a lot of research for blended and distance learning, research into the use of the online environment to supplement or enhance traditional teaching is a current, formidable challenge. One key concern resides in the possibility that students can easily become disoriented while engaged in the learning process due to the lack of embedded guidance and structure of the online contents even though these students may receive some support and direction from their teachers across distance (Cowley et al., 2002). In this regard, Moore et al. (2011) argued that the online learning environment lacks the structure and guidance usually found in face-to-face and traditional teaching-learning environments. This is an important contemporary educational issue that needs further attention and investigation.

1.2 The problem and the context

Science students often develop poorly defined concepts that are abstract and intangible (Peterson et al., 1989). Specifically, misconceptions related to heat, energy and temperature (Alwan, 2011; Nottis et al., 2010; Prince et al., 2012), and the different states of matter (phase change) (Driver et al., 1978; Shepherd et al., 1982) are widely documented in the literature. Chi (2008) categorizes misconceptions at different levels and suggests that instruction should be targeted at the appropriate level to foster conceptual change. Specifically, misconceptions at the highest level are difficult to correct by simple refutation and through standard instruction strategies. Traditional classroom settings with lecturing as a predominant mode have failed to provide adequate support and environmental accommodations to correct the conceptual basis of these misconceptions (Deslauriers et al., 2011; Prince et al., 2012). This is likely to be due to the fact that traditional classrooms consist of large numbers of students, therefore it is difficult to meet the learning needs of each individual and has thus failed to provide students with adequate experiences through normal instruction that foster an understanding of these science concepts. Therefore, student's ability to achieve a sound conceptual understanding of abstract science concepts seems limited (Sawyer, 2005). Logically then, educators are considering alternative paths to address this contemporary issue pertaining to the need to provide adequately for each individual and facilitate deep engagement and learning. Therefore, many educational and governmental bodies support the adoption of student-centred strategies based on research findings that demonstrate that the strategies used to promote active learning through student interactions lead to gains in learning in STEM courses (Freeman et al., 2014; Singer & Smith, 2013; Stains et al., 2018).

Advancement of technologies offers educational researchers opportunities to provide online learning environments that stimulate high engagement and deep learning (P. S. Chen et al., 2010). Indeed, the educational community is embracing the online learning environment as a potential solution to support students' effective learning in parallel with the classroom environment (Garrison et al., 2004;). In particular, web-based learning approaches and their integration into the science classroom have become a central focus for the educational community over the past few years (Kim et al., 2011).

Despite decades of research, the methods for successful implementation and use of the technologies are still providing a formidable challenge in areas such as science education. For example, sophisticated simulations that allow students to explore major conceptual ideas in science are becoming available, but reframing the educational setting so that students can, and do, take advantage of the opportunities they offer frequently remains beyond reach. There is, in particular, a growing need for the establishment of online inquiry environments for students who are learning without immediate human support. This area of research demands further attention. Specifically, the level of scaffolding embedded in activities to promote students' active engagement towards meaningful learning, requires further investigation.

Recent studies have increasingly focused on two educational problems in the context of online learning (K. Meyer, 2014). These pertain to student engagement and the quality of instructional guidance embedded in online contexts. For example, Schilling (2009) stated that student engagement is the key element of meaningful learning in online courses. Indeed, students need to engage actively with the learning activities for the meaningful construction of knowledge (K. Meyer, 2014). Learning in online settings occurs when students are actively engaged with the content by interacting with the environment (K. Meyer, 2014). In this process, instructional guidance plays an important role in securing student engagement (R. B. Mason, 2011). This highlights, as researchers have stressed, the importance of using suitable instructional guidance for effective learning (Fisher, 2010; K. Meyer, 2002) because it becomes the key element promoting students' active engagement. These research studies form the basis for the current study in the context of the implementation of independent online learning in the absence of a teacher or peer support through the inquiry modules on offer.

1.3 **Purpose of this study**

The purpose of this study is to explore the ways in which pedagogical practice can help make learning modules more useful for increasing the level of student engagement and learning in a self-directed online environment. To achieve this goal, the following three research questions have been formulated for this study:

RQ1. What role can scaffolding play to facilitate student learning in online learning modules?

RQ2. What factors influence student engagement in their exploration of the learning modules?

RQ3. What learning approaches do students apply in understanding the science concepts?

These questions have guided the process of developing a methodological framework for collecting and analysing the data for this study.

1.4 **Research design**

Student active engagement in online learning depends on the pedagogical design, the provision of educationally purposeful activities, and clear guidance relating to what they need to do and achieve (K. Meyer, 2014). Previous studies have demonstrated that students' have shown 'shallow' participation in online environments due to the lack of adequate guidance (Tallent-Runnels et al., 2006). Consequently, in this study, a framework has been developed based on the *predict*, *observe* and *explain* (POE) scaffolding strategy to probe thinking and guide students while they are undertaking the online activities.

The POE scaffolding framework is underpinned by both individual and social constructivist theories and supports inquiry learning (White et al., 1992). The notion of cognitive disequilibrium (Piaget, 1985) is used as the key concept in the POE framework to prompt students' initial ideas, motivate them to engage in conceptual inquiry and, in this process to embark on investigations (White et al., 1992). Provoking cognitive conflict can lead to effective learning by prompting learners to articulate and explore ideas and theories that they hold about a concept (Treagust et al., 2014). As such, the POE scaffolding strategy has the potential to be an effective scaffolding model for online learning in a self-directed environment.

In an online self-directed environment, it is important to create a response system that can provide students with synchronous feedback as a replacement for immediate teacher support. In an endeavour to ensure this support occurs, the POE framework has been extended to incorporate an additional *evaluate (E*) phase. At this point, students receive feedback on their responses that can assist them to clarify and evaluate their understanding. Therefore, the extended POEE scaffolding framework can guide students across the four stages. These are: a) elicitation of initial ideas and outline the prediction (*predict phase*); b) interaction with the modules to investigate the prediction (*observation phase*); c) understanding and explaining the concepts (*explain phase*); and *d)* clarifying and evaluating their understandings. The details of the design and development of the POEE scaffolding framework is discussed in chapter 3. The diagram below illustrates the research focus of this study:

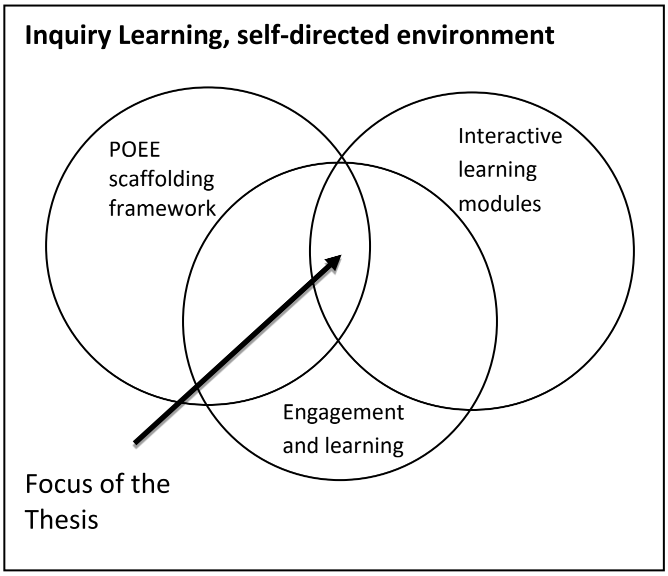


Figure 1-1: Focus of this study, adopted from Kearney (2002)

This study uses a qualitative data dominant mixed method research approach to investigate the students' engagement and learning approaches in the POEE supported online modules. This method is used to gain an insight into the dynamics of learning occurring for the students as they engage with the content and the learning processes in the self-directed environment. Its purpose is to enable a deeper understanding of various aspects of the students' interaction with the POEE tasks including the key scaffolding elements and supports embedded in the learning modules. From the above figure 1-1, it can be perceived that the study being undertaken is comprised of four key aspects, that is, a) design and use of the POEE scaffolding framework, b) design and use of online learning modules, c) student engagement and, d) student learning approaches.

Online inquiry learning requires an environment in which students are provided the freedom to learn while receiving adequate support (Garrison, 2003). In this self-directed environment, various scaffolding strategies are embedded within the modules under the umbrella of the POEE scaffolding framework. Scaffolding, as it was originally devised, is a technique that supports the students during learning processes by providing them with "just in time" support to solve a problem that cannot be accomplished without that support (Wood et al., 1976). In a typical learning environment, scaffolding is guided by teachers/instructors, sometimes referred to as "more knowledgeable others" (MKOs) (Vygotsky, 1978). But, in this study, scaffolding is conceptualized as an interaction between the students and sophisticated technology (Lumpe et al., 2002). As such, the scaffolding strategy, which implies interactions between an MKO and an apprentice, has been mimicked through the adoption of sophisticated technology to support students' engagement and learning (Sharma et al., 2007). The rationale for providing this scaffolded support is to facilitate students' deep engagement and learning. For this purpose, three other key scaffolding elements employed in this study are multiple external representations (MERs) (Gilbert, 2008), instructional guidance and inquiry questions to promote students' inquiry.

The multifaceted advantages of technology extend the parameters of teaching possibilities thus facilitating student learning of abstract science concepts that are often difficult to teach adequately in classrooms or laboratories (Lyons, 2012). For example, MERs (simulations, videos and other visual representations) become an effective tool in the domain of abstract science concepts to facilitate students' reconstructing their initial ideas through the visual experiencing of events (Wieman et al., 2008). It thus allows students to make detailed observations of events and also provides an opportunity to experience these visual representations repeatedly (Kearney, 2003). Because of their potential to enhance student learning, science educators are increasingly focusing on how to integrate these visual representations into instructional resources while ascertaining what conditions offer the most efficient forms of learning (Barak, 2013). For example, research shows that visual representations are useful for learning only when they are well-structured and integrated into the program with careful consideration being given to the locations where they might be embedded to provide optimum assistance (Schnotz et al., 2005).

In addition to opportunities being provided for visual interactions, inquiry environments require instructional guidance for effective learning (Belland, 2014). This study provides different types of instructional guidance to assist learners to succeed on more complex tasks. For example, strong, moderate and open/minimal guided support have been employed to investigate their impact on students' engagement and learning. In the learning modules, guided activities facilitate student understanding of the complex phenomena of embedded simulation models. In contrast, unguided activities provide opportunities for them to gain experience and improve skills and understanding (Reiser, 2004). In addition, several inquiry questions and prompts have been employed to guide students' inquiry. Details of the instructional guidance and the nature of inquiry questions and prompts are discussed in chapter 4.

In brief, a learner-centred online environment has been designed and developed to promote student learning without teacher support. Two online learning modules on the topic of *Heat* and *Phase change* have been designed for students to learn in the self-directed online environment. Each module incorporates a number of features including the following:

- design of the modules is grounded on the extended POEE scaffolding framework;

- use of sophisticated technology such multiple external presentations (simulations, videos, animations and others) has been made available to students to facilitate the experience of interacting with abstract science concepts;
- learning modules are designed by offering varying levels of guidance from strongly guided to open-ended explorations incorporating different question and prompts.

This study draws upon qualitative data methods, in particular, the stimulated recall interview, video recordings of student activity, observational notes and students' written responses. A thematic analysis procedure has been adopted to unpack the data gathered in response to the research questions. The findings of this study have the potential to construct new knowledge with implications for the use of carefully designed and structured online modules in the current educational context.

1.5 Significance of the study

This study draws on cognitive constructivist theories to inform the development of an online inquiry-based learning environment that facilitates students' engagement, interaction and learning of abstract science concepts through self-directed activities. Very few published studies address self-directed, inquiry-based learning activities that involve the use of multimodal representations where the personal, direct input of teacher or peer support in the online context is absent. To achieve this scaffolding, this study implements an extension of the well-known POE strategy (White & Gunstone, 1992) into a new learning situation, namely inquiry-based online environment. The novel element is the introduction of the evaluate (E) phase to create a self-guided online learning environment. This extended POEE strategy signifies a new development in scaffolded learning modules on science concepts by integrating: the notion of cognitive disequilibrium (Piaget, 1985); instructional guidance (Clark, 2009); multiple external representations (Gilbert, 2008; Johnstone, 1993); and inquiry questions (Chin, 2006, Craig et al., 2004, Ge et al. 2004). It also contributes to studies exploring the nature of pedagogical support that promotes students' active engagement on the constructs of behavioural, cognitive, and attitudinal engagement (Fredricks et al., 2004; Fredricks et al., 2016; McGowan et al., 2010).

The outcomes of this study have distilled several practical implications based on observations and data. Firstly, it was observed that students' inquiry skills relied substantially on their ownership of their learning and their self-regulated inquiry skills, this builds on findings of prior studies (Fang & Hsu, 2017; Raes & Schellens, 2016). It is known that students often lack these self-regulation skills and fail to acquire them from traditional teacher-supported environments (Azevedo, 2005; Raes et al., 2012). It was also found that students' prior knowledge and misconceptions influenced their inquiry processes which aligns with previous studies (Kirschner, Sweller, & Clark, 2006). Nevertheless, being constructivist in nature, inquiry-based learning satisfies four essential criteria including elicitation of a student's prior knowledge, creating cognitive dissonance in their mind, providing them opportunity to apply the new knowledge, and supporting their reflection and clarification during the learning process (Baviskar, Hartle, & Whitney, 2009). The current body of science education research is lacking recommendations in regard to how the technology-mediated scaffolding should support science inquiry to provide self-regulated and constructivist environments online in the absence of direct teacher scaffolding. The exploration of different forms of scaffolding in this study to support self-directed online learning environment in the form of two learning modules based on introductory science concepts attempts to address this issue.

Secondly, the roles of external representations, inquiry questions and instructional guidance as forms of scaffolding to facilitate students' cognitive thinking have been investigated to explore whether these cognitive tools mitigate the needs of immediate teacher supports in the online context. Modern technological tools represent platforms that can scaffold inquiry processes and produce effective and efficient learning situations for students (De Jong, 2006). Numerous published studies have been conducted to understand different aspects of inquiry processes, instructional guidance and enhancing students' understanding of inquiry processes through online, web-based content or software-based virtual environments (Brenner et al., 2017; Bumbacher, et al., 2017; Geelan & Fan, 2014). Most of these studies were set in learning contexts where teachers were present with students and did not focus on students' independent inquiry learning in a self-directed online environment for learning science concepts. Therefore, this study explores the implications of adopting the technology-mediated self-directed online learning environment for students' inquiry learning without considering the immediate support from the more capable others.

Third, transforming the traditional learning environment and translating the traditional learning content to enable their deployment online for students' independent study demands ongoing investigations since the nature of technology is changing rapidly. Studies on educational technology have shown that innovative technology-rich curricula can provide great opportunities for engaging students in inquiry practices (H. S. Lee et al, 2010). However, due to many technological and pedagogical limitations, it is often difficult to implement an inquiry-based online learning environment effectively. Although some studies have identified the challenges and constraints in this regard (Fang & Hsu, 2017; Kim, Hannafin, & Bryan, 2007), few have elucidated strategies that address the transformation of traditional teaching environments into computer-based environments (Chang, 2013). Therefore, this study addresses this area of ongoing research and provides an evidenced exemplar of how to design and implement an inquiry-based learning module in an online environment.

Finally, this study attempts to integrate cognitive conflict questions and other inquiry questions to satisfy students' intrinsic motivational needs and promote students' engagement in a new environment of inquiry learning. In their study, Chen and Jang (2010) specifically considered the lack of research work relating to motivational support in online contexts. In self-directed online learning, motivational factors are of great interest for exploring student engagement since this environment requires a high level of independence and self-direction (S. W. Lee, 2013; Zimmerman & Kulikowich, 2016).

1.6 Outline of the thesis

Chapter 1 Introduction: This presents the motivation, background and statement delineating the research problem. It provides the context of the problem and identifies the purpose of the study. It overviews the methodological base and research design. It also discusses the significance of the study in its relationship to inquiry learning focusing on abstract science concepts in the context of an online environment.

Chapter 2 Literature Review: A literature review of research is presented synthesising the wide range of topics of importance impinging on this study. Amongst them is the research that has been undertaken on inquiry learning for science education in the online context. Second, an overview of the use of scaffolding approaches employed in science education is provided. Finally, the literature in the field of student engagement and approaches for promoting engagement in online settings has been cited and related to the context of this study. Evaluation of this literature also sheds light on research gaps in the field of the study being undertaken.

Chapter 3 Research Methodology: The research methodology of this study is presented in the service of the conceptual and methodological frameworks upon which this study is built. These are the constructs of scaffolding, student engagement and learning approaches. Moreover, these are conceptualised and linked to student interactions in online settings. In addition, the chapter delineates the research method governing the nature of the research and the resultant techniques employed for the collection and analysis of data. The details of principles and activities reflective of the methodology influencing this research such as the description of online settings, participants, procedures of data coding, and ethical considerations are discussed.

Chapter 4 Learning Modules Design: This chapter discusses the online learning settings and informs the design, theoretical basis, and development of the learning modules activities. The scaffolding elements employed in the learning modules supporting student engagement and learning under the scaffolding framework are formulated. Centrally, the design and use of multiple external representations, the nature of the instructional guidance provided are discussed; how these are used to design and develop the learning activities are also explained. Based on the theoretical basis and design framework formulated in this study, the development of two learning modules *Phase change* and *Heat* module has been described.

Chapter 5 Scaffolding and the Role It Plays in Online Learning: This is the first of three results and analysis chapters. The results emerging from the exploration of the various scaffolding strategies used in the learning modules in online settings are presented in this chapter. The findings of this study ascertain whether the addition of the 'evaluate' phase to the original POE model has the potential to be an effective scaffolding strategy for online learning. The importance of multimodal scaffolding, instructional guidance and the use of multiple external representations has been discussed. The findings also explore issues emerging during the student activities that pertain to the scaffolding elements used in online settings.

Chapter 6 Student Engagement: The findings of the various constructs of student engagement and the factors that influence student engagement in online settings are presented. The constructs of student behavioural, cognitive and attitudinal engagement, such as time-on-task, the degree of effort students dedicate to the task, ability to follow the instructions, cognitive effort across the activities, interest towards task completion, students' preferences on instructional guidance including use of representations, and so forth are considered to find the level of student engagement in the learning modules. It was expected that the instructional guidance provided would affect students' behavioural and cognitive engagement positively. Moreover, the contribution of multiple external representations, as an effective scaffolding element that can facilitate student engagement is also evaluated. In this process, the discussion explores the trade-off between engagement and cognitive overload wrought by representations creating a high workload demanding physical responses that could negatively impact on student engagement.

Chapter 7 Learning Approaches: This chapter focuses on the students' approaches to learning and sheds light on the effects that the various scaffolding strategies produce on the participants' learning approaches and understanding the concepts. The perspectives of students' background, such as their previous chemistry knowledge and prior experience with online learning, and how these influence their engagement and learning are discussed in this context.

Chapter 8 Discussion and conclusion: The findings revealed and explicated in the previous chapters are revisited to obtain an overall picture of the findings and to link these to contemporary educational issues. The implications of the present study for online learning in the field of science education are discussed. A summary, conclusions, and recommendations for practice from the study are provided. In addition, some suggestions for future research studies that build on the findings from this research are also provided.

1.7 **Conclusion**

The changing learning environment is discussed in the chapter. Currently, educators are paying significant attention to online learning due to rapid technological change and the increasing availability of sophisticated technology which is increasing the viability of education in this mode. Especially in the science domain, technological innovation has contributed to the development of plentiful educational resources. So, it is timely, that the issue of extending the opportunities for a quality education through gaining access to online learning resources by all, including those in a traditional classroom where large student numbers militate against many students receiving the educational differentiation they require to be successful, be discussed. It remains nevertheless a huge challenge to provide students an online learning environment where they might engage and learn effectively. How this challenge might be met in the science education domain is a central theme underlying this study.

Chapter 2
Literature Review

The aim of this literature review is to describe how inquiry learning, where scaffolding has been incorporated into its fabric, is applied in online learning contexts. In addition, the aim is to reflect upon the construct of student engagement and the various learning approaches employed in the evolving learning context of science education.

2.1 Introduction

All forms of learning are contingent upon how the learner's mind is perceived. This is a pivotal platform upon which the direction of the majority of educational research that deals with student learning is pursued. In this regard, Cunningham (1996) has proposed three models that are related to learning and cognition: the mind as computer; the mind as brain; and, the mind as rhizome. Based on these metaphors of mind, Bonk et al. (1998) derived three key approaches by which learning is transacted: (a) learning as information processing which is translated as a cognitive skills approach; (b) learning as experiential growth and pattern recognition which is the crystallization of a cognitive constructivist approach; and (c) learning as a sociocultural dialogic activity which is derived from a social constructivist approach. Bonk et al. (1998) further stated:

> If learning is predominantly information processing, then instruction should provide for efficient communication of information and effective strategies for remembering. If learning is predominantly experiential growth, then instruction should focus on experiences and activities that promote the individual development of the appropriate cognitive networks or mind maps. And, finally, if learning is predominantly a sociocultural dialogic, then instruction should provide opportunities for embedding learning in authentic tasks leading to participation in a community of practice (p. 26).

The last two approaches, as mentioned above, for viewing how development and learning occur are respectively known as cognitive constructivism and social constructivism (Cobb, 1994). Cognitive constructivism, which draws its inspiration and substance from Piaget's pioneering developmental studies and the work of neo-Piagetians, focuses on individual constructions of knowledge (Piaget, 1952). In contrast, social constructivists referencing, in particular, the work of Vygotsky (1978) asserts that learning and development are connected and constructed from the particular sociocultural contexts in which we inhabit and where individuals are enculturated into the cultural and psychological tools of that society (Moll, 1992).

In the construction of new knowledge, individual constructivism involves the processes of assimilation and accommodation (Piaget, 1952). For example, when a person already knows the fact that a metal feels colder than plastic at room temperature, his cognitive balance is in a state of equilibration. However, if an individual were to find that both the metal and the plastic actually have the same temperature, the mind's cognitive balance is upset causing a state of disequilibrium in the process of moving to a more complete schema and a new state of equilibration. According to Piaget, this change process from a state of disequilibrium to one of equilibrium occurs through the processes of 'assimilation' and 'accommodation'. Assimilation refers to the integration of new knowledge into an existing schema. In contrast, accommodation is transacted when the new knowledge is incompatible with the existing schema; as a result, the existing schema is revised to form a new schema to address the cognitive discrepancy.

Similar to individual constructivism, Vygotsky (1978) viewed the construction of knowledge to be based on prior knowledge, but centrally the construction of new knowledge is influenced by the social context in which the learner lives, interacts and engages in discourses with others who are more knowledgeable of the psychological and cultural tools being accessed in a particular context (Pritchard et al., 2010). One central concept rooted in his theory is the notion of the zone of proximal development (ZPD). Vygotsky describes ZPD as "the distance between the actual developmental levels as determined by independent problem solving, and the level of potential development as determined through problem-solving under adult guidance, or in collaboration with more capable peers" (Vygotsky, 1978, p.86). The ZPD captures the notion that higher levels of achievement can occur when support, by a more knowledgeable other (MKO) is provided. This support may be provided verbally but also through a range of cultural tools such as technologies, languages (e.g., Braille), visual tools (e.g., concept map), various texts including books all of which act as "symbolic mediators" into the development of more complex cognitive structures (Kozulin, 2005, p.23).

Constructivist theories have directly influenced the teaching and learning of science, articulating learning as an active process of constructing knowledge rather than by acquisition through transmission. Instruction in this context is a process of supporting that constructive process (Duffy et al., 1996). This notion of constructivism has been frequently invoked as the reason for substituting the traditional teacher-centred teaching approach by learner-centred instruction where the focus is on a teacher guiding and supporting students as they learn to construct their understanding of the culture and communities of which they are a part (Bonk et al., 1998; Cobb, 1994; Duffy et al., 1996). For example, based on the Vygotskian constructivist notion, Hodson et al. (1998) state that the students' understanding of the construction of scientific concepts reflect their perceptions of how the world is constructed around them. Similarly, Vosniadou et al. (1998) observe that initial conceptual understanding can change as a result of learners' enriched observations of the enveloping world. Within the science domain, Driver et al. (1994) suggest that learning can be achieved by the co-construction of scientific knowledge by teachers and students, and in that process, students need help from their teachers in understanding the symbolic world of scientific concepts. When applied to pedagogy, this interaction between teacher and students could be realised in the context of inquiry-based learning (Xinxin, 2015).

2.2 Inquiry learning in science

Inquiry learning is rooted in both individual and social constructivist theories in which students need to actively participate in constructing knowledge rather than acquiring it through direct instructional support. John Dewey, a former science teacher from the early 1900s who was an advocate of inquiry learning, argued that children should not receive knowledge passively but rather they should experience the science to encourage thinking as an attitude of mind (Dewey, 1910). Dewey emphasized the doing of science, as opposed to knowing science, with the expectation that students could construct their own knowledge (Dewey, 1910, 1938). Following in the footsteps of Dewey, other academic educators continued to emphasize students' active involvement in the learning process through meaningful investigations rather than students being the passive recipients of science facts (Rutherford, 1964; Schwab, 1966; Welch et al., 1981). Over the past three decades, a plethora of research studies have been conducted indicating that there is substantial empirical and theoretical evidence revealing that scientific inquiry can facilitate meaningful knowledge construction leading to higher achievement for students (Bybee, 2006; Russell et al., 2011). For example, studies have found positive effects of scientific inquiry on students' conceptual change and understanding (Geier et al., 2008; Lewis et al., 2008;); the development of cognitive abilities (Bybee, 2000; Gerber et al., 2001); and promoting more sustained engagement (Lynch et al., 2005) as well as the realisation of other positive contributions in different science subjects.

Despite the agreed importance of inquiry learning, critics are continually challenging the effectiveness of inquiry learning arguing that its minimally guided approach does not offer necessary structure to help students learn the important concepts and procedures of science (Kirschner et al., 2006). They often characterize the role of teacher in inquiry learning as staying in the background while students engage in self-regulated, hands-on activities as being of dubious value (Kirschner et al., 2006). These critics have advocated for direct instruction in which teachers deliver content to students through carefully designed lectures and practical activities (Furtak, et al., 2012). While the debate regarding the relative success of inquiry-based and traditional instructional approaches has been sustained, researchers are continually embarking on studies that explore the various dimensions of research and practice to develop and formulate frameworks to create the most efficacious inquiry environments for teachers and students. For example, due to the increasing adoption of technology in learning, online learning environments are becoming more prevalent. Examples in this context include: a community of inquiry framework (Garrison et al., 1999); a pedagogical framework for technology-enhanced inquiry practice (Kim et al., 2007); a scaffolding design framework for software to support science inquiry (Quintana et al., 2004); hypermedia-assisted learning (HAL) environments (Shapiro, 2008); a framework of learner centric ecology of resources (Luckin, 2008) and so forth.

It is important to point out that instructional support approaches in inquiry settings can be formulated under the influence of both individual cognitive constructivist and social constructivist perspectives. Due to rapid technological advances, a wealth of educational resources such as simulations, animations and other visual resources, influenced by a cognitive constructivist perspective, and blogs, online forums, shared learning environments designed on the back of social constructivist perspectives are constantly evolving allowing students the opportunities to explore individual interests and to build upon prior experiences in open learning spaces. Moreover, many technology tools enable educators to structure learning activities that target student misconceptions, prompt students to elaborate their responses, and pose questions to encourage them to think more comprehensively and deeply about targeted concepts and ideas. The following sections of this chapter highlight this contextual change of instructional support citing and describing the relevant literature.

2.3 **Pedagogical practice for science inquiry learning in the online environment**

Inquiry learning is supported in online environments due to the multifaceted functionalities inherent in this mode and the non-linear structure of the web-based environment. This versatility promotes an opportunity to create inquiry learning within the web-based content. However, for these benefits to be realised, an appropriate inquiry learning context that allows access to well-informed pedagogical design is imperative. Perhaps, the challenge resides in how to create an online environment that encourages self-regulation in students to engage in independent study.

Some of the significant successes in instructional design to facilitate inquiry-based learning online have arisen when addressing students who were working collaboratively with peers. Little attention has been paid to how students engage in individual learning through these initiatives. Sun and Looi (2013) designed a pedagogical model focusing on collaborative science inquiry for web-based inquiry learning. Though it was intended to provide multiple sources of scaffolding informed by POE instructional design and other relevant design aspects of inquiry-based environments, it focuses mainly on synchronous social interactions without providing much attention to students' independent study patterns. Raes et al. (2012) used information problem solving using the internet model (IPS-I-model), a pedagogical design for learning science in classroom settings in parallel with the online environment through a collaborative inquiry project. In their study, they only considered evaluation of student understanding of the content area and did not consider student knowledge of the technology being used and their interaction with them. Students' knowledge and experience with technology are important parameters for their success in this environment. In a separate study, the researchers designed scaffolded technology to enhance science inquiry in a computer-supported collaborative inquiry learning (CSCL) environment using a teacher-led high-structured condition in comparison with a low-structured condition (Raes & Schellens, 2016). A further study examined the effects of embedding pedagogical support of continuous and faded computer-based procedural scaffolds, alongside teacher supported scaffolds either at the beginning or towards the end of the activity (Wu & Pedersen, 2011). These studies focused purely on the collaborative nature of the pedagogical design in the inquiry learning environment.

To ensure greater congruence with students learning needs, researchers have attempted to develop several online platforms and simulation environments by employing different pedagogical designs to facilitate student engagement and their inquiry learning. The intention is to provide an open and free environment that educators can adopt in the development of their inquiry curriculum using these online platforms. The following table 2-1 summarises most of the popular online inquiry-based learning environments that have been designed for learners across the different science domains:

Table 2-1: Examples of online inquiry environments

Inquiry Environment	References	Pedagogical design
Physics Education Technology (PhET)	(Perkins et al., 2006); (Wieman et al., 2008)	PhET supports a guided-inquiry approach with a stand-alone simulation tool. It can be employed in any web-based inquiry learning environment with related pedagogical designs.
Molecular Workbench (MW) from the Concord Consortium and other projects	(Pallant et al., 2004; C. Xie, 2008)	MW supports a guided-inquiry approach incorporating feedback, reporting, and reflection. It can be used as either a stand-alone simulation tool or within a web-based inquiry learning environment.
Web-based Inquiry Science Environment (WISE)	(M. C. Linn et al., 2003; M. C. Linn et al., 2000)	WISE supports guided and collaborative inquiry across several inquiry phases such as online discussions, data collection, drawing, argument creation, resource sharing, branching, concept mapping etc.
GoLab	(Govaerts et al., 2013)	This platform supports guided inquiry: comprised of five inquiry-learning stages; orientation, conceptualisation, investigation, conclusion a and discussion
weSPOT	(Mikroyannidis et al., 2013)	weSPOT supports guided inquiry comprised of six inquiry phases; Hypothesis generation, operationalisation, data collection, data analysis, interpretation and communication
ThinkerTools	(B. Y. White, 1993; B. Y. White et al., 1998)	This tool supports guided inquiry: comprised of six inquiry cycles; questioning, hypothesizing, investigating, analysing, modelling, and evaluating

WebQuest	(Dodge, 1995); (Milson et al., 2001)	WebQuest supports guided inquiry: comprised of five inquiry stages: introduction, task, process, evaluation, and conclusion

Web Integrated Science Environment (WISE) is one of the most widely used online collaborative inquiry learning environments for students, working both as individuals and in groups. It integrates technology and web-based inquiry pedagogies that facilitate student's development of problem-solving skills by supporting them in generating predictions, conducting investigations, and using scientific evidence to create arguments (M. C. Linn et al., 2003). WISE integrates an inquiry map into the environment to support students while they are investigating a topic. Though it supports students' self-regulated learning, the collaborative nature of the learning environment created is the foundation for this platform and is promoted during the inquiry process. ThinkerTools is another example of an online inquiry environment that helps students to build mental representations by scaffolding their scientific investigations through six cycles: questioning, hypothesizing, investigating, analysing, modelling, and evaluating. During each inquiry cycle, the activity is scaffolded by the technology as well as by peers and teachers who can provide procedural and strategic support to students (B. Y. White, 1993). Thus, students' independent inquiry processes are largely overlooked in this learning environment as students are supported by their teachers during the inquiry process online.

GoLab and weSPOT (Working Environment with Social, Personal and Open Technologies for Inquiry-Based Learning) are online environments aimed to help students to engage in science topics and become acquainted with scientific inquiry methodologies through the use of remote online laboratories (Govaerts et al., 2013). GoLab enables the inquiry-learning process comprised of orientation, conceptualisation, investigation, conclusion, and discussion cycles. weSPOT promotes scientific inquiry as an approach for science learning and teaching in combination with existence curricula and teaching practices (Mikroyannidis et al., 2013). Similarly, Co-Lab is another collaborative learning environment where learners can experiment with the help of computer simulations and remote laboratories, and express acquired understandings in a computer model (van Joolingen et al., 2005). WebQuest is a web-based environment that offers access to online sources, a structure for evaluating these sources, and teacher supervision in identifying appropriate and relevant content (Dodge, 1995). WebQuest is comprised of five stages: introduction, task, process, evaluation, and conclusion (Milson et al., 2001). These online inquiry learning environments clearly advocate collaboration during the inquiry process. The environment supports synchronous communication, however, for self-directed inquiry environment students might not avail that opportunity. Also, the constraints of online inquiry environment indicate that it may not be suitable as the primary medium of learning. Differences in digital skills may disadvantage some students. Additionally, differences in prior experience with the environment might also serve as an impediment for other students. So, a crucial challenge is to offer a degree of embodiment within the design, that is available in a face-to-face setting (Dickey, 2005).

Several other additional inquiry learning environments have been developed to meet specific discipline objectives within the science domain. For example, SimuLab is a specially designed cognitive tool that provides chemistry students with a low cognitive load environment. It moves students' thinking from lower order cognitive skills (performing laboratory procedures) and directs students' attention towards the highly relevant higher-order cognitive processes (to predict and support hypotheses) which provide them more scope for scientific reasoning (Josephsen et al., 2006). The nature of this simulation environment is limited towards student's cognitive engagement and thus omits other important aspects such as the how this engagement relates to a student's behavioural and attitudinal constructs in the online environment. There are also many other examples of studies of online inquiry environments such as: 'Connected chemistry' Interface within 'NetLogo' modelling environment (Stieff et al., 2003); 'SIMQUEST' which allows for the study of the effects of instruction on collaboration and multiple representations (Saab et al., 2007); classroom versus WebCT course in an on-line asynchronous discussion (Limniou et al., 2009); chemistry knowledge and spatial abilities (H. Lee, 2007); a simulation program 'Starry Night™' that addresses conceptual understandings (Trundle et al., 2010); collaborative versus individual use of regulative software (Manlove et al., 2009); student cognitive, emotional, and behavioural engagement with 'Physlets' (H. K. Wu et al., 2007); and so forth. Thus, online inquiry learning environments are providing ample opportunities for students to engage in a meaningful way and have been designed with specific intended learning objectives. Researchers are actively incorporating these pedagogical designs into their classroom teaching or using them in parallel to complement formal classes (blended learning). However, most of these initiatives represent pre-designed teacher-led inquiry practice and collaboration thus limiting the ability to experiment beyond the affordances provided by the online environment. Students' independent study approaches and engagement with the inquiry process have not been sufficiently studied and thus further investigation is warranted. Specifically, research that informs how the technology-enhanced pedagogical design might scaffold learning during science inquiry in the online environment when students are self-directed (without teacher support), is lacking. The instructional design and the research described in this thesis attempts to address this gap by adopting stand-alone simulations to apply a pedagogical strategy that scaffolds students' self-directed learning through the inquiry learning process.

Due to the inherent benefits of PhET and MW simulations (see table 2.1) as well their stand-alone availability, this study adopts science simulations from these two well-established sources.

They can be employed as part of pedagogical design in any web-based inquiry learning module and are accessible for teachers. Pedagogically, PhET simulations have been demonstrated as successful in reducing cognitive load during the learning process as evidenced in several research studies (Akaygun et al., 2013; Adams, 2010). Akaygun et al. (2013) examined the consequence of interactivity in solubility and equilibria in the features of animations and simulations. They found that in both cases, students did not experience a high cognitive load during learning, and indeed, they demonstrated positive attitudes towards both forms of activity. The results also showed that simulations bring significant changes in student mental models at both the macroscopic and molecular levels. Adams (2010) focused on aspects of simulations such as the importance of showing the unseen, and through the use of analogy and effective guidance levels. This work investigated how students used PhET simulations to construct their conceptual mental models and the effects of embedding various degrees of guidance. The study also revealed that showing the unseen and use of analogy equally facilitated construction of students' understanding.

Molecular Workbench (MW) simulations provide visual, interactive computational experiments for teaching and learning science. This particular inquiry-learning platform led several researchers into attempting to foster students' development of mental models of abstract science concepts and facilitating their molecular reasoning skills. To visualize this unseen world, Molecular Workbench (MW) created a simulations' environment at the sub-microscopic level of the substances. This approach provides a potential process for eliminating student misconceptions, developing students' mental models and to help them consolidate ideas and experiences they have had with the unseen world (Pallant et al., 2004). Using MW, Levy (2013) designed a technology-enhanced curriculum module in which high school chemistry students conducted virtual experiments with dynamic molecular visualizations of solid, liquid, and gas. The results showed the benefits of interacting with dynamic molecular visualizations by improving students' molecular reasoning.

In brief, this current study adopts PhET and MW simulations due to their stand-alone availability and their ability to facilitate students' developing effective mental models of science concepts. Within a constructivist-based interactive learning environment, these two platforms provide affordances to explore and manipulate several apparatuses within the environment allowing learners to explore and inquire environments not easily replicated in a traditional classroom setting. However, these two simulation environments are not without constraints. Learners cannot examine or use the equipment beyond the affordances provided by the simulation environment. Additionally, there is a little or no opportunity for kinaesthetic and tactile experiences. Therefore, these simulation environments, generally, are not suited for those inquiry processes in which tactile experiences (e.g., touch or feel the object) are known to be an essential part of the learning process. Sciences instructors often espouse that physical manipulation is more effective when learning abstract science concepts (Druyan, 1997). It is argued that something touched is more real than something seen (Schmidt et al., 2013).

2.4 Online inquiry as self-directed learning

Self-regulation is an important component of self-directed learning that has received growing attention of researchers in online contexts (Lin et al., 2015). Online learning is supported by the constructivist approach as it provides a greater degree of autonomy and initiative to the learner during the learning process (Thompson et al., 1996). The very nature of the online environment encourages autonomous learning, that is, students are required to be more independent in this context (Serdyukov et al., 2013). Students need the ability to regulate, manage, and plan their activities even more so than classroom learners who have ready access to a more knowledgeable other (MKO), a teacher who can provide in the moment support (Ally, 2004). Since students working in an online learning environment need to have acquired a degree of autonomy for successful learning, the ability of learners to engage in self-regulation is an important factor to consider (Barnard et al., 2009; C. H. Wang et al., 2013). This self-motivated regulatory process is known in the literature as self-regulated learning (Broadbent et al., 2015; B. J. Zimmerman, 2008).

However, the current body of research in this field has revealed that most students have difficulty regulating their learning when performing metacognitive activities (Lazonder et al., 2008). Self-regulation in online learning is difficult without direct teacher support as students dealing with hypermedia in online environments, need to make decisions about many facets of learning such as what to learn, how to learn it, how much time is needed to spend on learning, how to access and use instructional materials, and to determine whether they understand the material (Azevedo, 2005). Students in classroom contexts rely on teacher support in monitoring these aspects of learning. Unsurprisingly then, the potential of hypermedia and online environments to provide consistently, supportive environments may be weakened by students' inability to regulate the crucial aspects of their learning (Jacobson, 2008). For example, they may not always activate prior knowledge, which is needed to anchor their learning of new material to previously learned concepts (Jacobson et al., 2008).

Research indicates that appropriate scaffolding can improve student self-regulation and learning in online environments. However, the nature of the most appropriate scaffolding support and the design principles of scaffolding remain unclear, changing from researcher to researcher. There is a dispute within the literature regarding whether the scaffolding design should be context specific or content specific. Some argue that scaffolding should be developed in design experiments focusing particular contexts (Cobb, et al., 2003), while others argue that scaffolding principles should support student performance in a content-specific domain (Kali & Linn, 2008; Quintana et al., 2004). There is a question of whether the same design principles that work in one context can be generalized into different contexts if research evidence supports this transfer (Belland, 2014). This question introduces the idea of the universal design principles of scaffolding, however, several studies argue against the idea of universal design principles of scaffolding in online environments (Pea, 2004; Quintana et al., 2004; Reiser, 2004). Keeping these arguments in mind, this study attempts to develop scaffolding frameworks considering the context (online learning environments) as well as some design principles (POEE scaffolding strategy) to support student performance in that context. Kali and Linn (2008) proposed several design guidelines for scaffolding science inquiry in which they focus on making science accessible, making thinking visible and promoting self-directed learning.

The above review of literature reveals that the online inquiry learning environment has shown promise as a means of facilitating student conceptual understanding; however, to work successfully in this mode requires carefully tailored scaffolding supports for self-regulation to occur and to act as a substitute for teacher support and face-to-face guidance. This area of research requires more attention. With the rapid changes in technology, the nature of pedagogical support in the online self-directed environment requires concerted investigation. The following section reveals the aspects of pedagogical support in the context of inquiry science that need due consideration of the nature of support required in the self-directed online learning.

2.5 Evolution of scaffolding in online inquiry

In face-to-face classrooms, the teacher's support is referred to as guidance so the body of literature about introducing inquiry learning into a traditional classroom or science laboratory refers to the degree and nature of guidance provided. Learning through inquiry in higher education is a complex, multifaceted process as new information and technologies are being increasingly adopted in the inquiry learning process (Ellis et al., 2005). Therefore, careful guidance and structure are required to integrate the supportive features within the technology-mediated environment to facilitate inquiry learning. Inquiry learning has several learning components, that is, hypothesis generation, experimentation, conclusion and evaluation. Each process in the inquiry learning needs support in the form of cognitive tools or scaffolds (van Joolingen et al., 2007). This process of giving support to students during online learning is referred to as scaffolding.

Scaffolding was first introduced and described by Wood et al. (1976) as the learning support that a more knowledgeable other (MKOs), teacher or peer, provides to the learner in a learning context to enable a learner to complete tasks beyond the learner's initial capacity. This concept of scaffolding was based on the notion of the zone of proximal development (ZPD) which Vygotsky (1978) defined as the gap between what a learner accomplishes independently and what can be accomplished with the assistance of a more capable other. This process of supporting the learner through the zone is known as scaffolding which might be manifested as a teacher's measured and appropriate intervention through verbal prompts, the provision of carefully selected materials, the opportunity to interact with peers or even a well-chosen computer program (Pritchard et al., 2010).

There is debate regarding what distinguishes a 'scaffold' from other instructional supports. Belland (2014) argues that different researchers would provide different answers to questions regarding scaffolding. Belland (2014) identified two key issues in defining the scaffolding in that he focusses on whether (a) scaffolding needs to be based on dynamic assessment and fading, and (b) domain-specific knowledge needs to be embedded in scaffolding. The key notion of scaffolding delineated from the work of Wood et al., (1976) is in its dynamic nature. Based on this understanding, studies show that dynamic customization of support is a key attribute of scaffolding (Conner & Cross, 2003; Van de Pol, et al., 2010) which leads to dynamic assessment, an ability to dynamically assess students' current performances (Ruiz-Primo & Furtak, 2006). Teachers can then use that information to customize scaffolding support and to provide students with just the right amount of support at the right time. However, dynamic assessment is not easy to implement (Ruiz-Primo & Furtak, 2006). It becomes more complicated when considering providing customised scaffolding support in online environments. The reason behind this complexity is the limited scope of computer-based scaffolds to engage in dynamic assessment (Belland, 2011). It is difficult for a computer-based scaffolding to dynamically assess student ability directly based on student actions as there might be multiple correct ways that a student could take at any given time during problem-solving (Belland, 2011). Therefore, it remains an open question of whether computer-based scaffolds need to display the criteria of dynamic assessment to be called as scaffolds (Belland, 2014). Some researchers argue that failing to provide dynamically adaptive support may fail to promote students' ability to independently complete the activity (Pea, 2004). Some also argue that it might cause cognitive overload for students who have already accomplished portions of the task effectively (Kalyuga, 2007; Schnotz, 2010).

Another important issue with regards to scaffolding support in an online environment is fading. Fading is the gradual removal of scaffolding support as students show evidence that they are capable of doing an activity independently (A. Collins, et al., 1989). However, the inability of computer-based scaffolds to provide dynamic assessment put a question mark to the appropriateness of the fading metaphor with computer-based scaffolds (Belland, 2014). Nevertheless, many studies attempt to employ fading in computer-based scaffolds to support students learning based on their feedback, in which researchers report that they no longer require support (Metcalf, 1999) or simply proceeds according to a predefined schedule to gradually take out the scaffolding supports (McNeill, et al., 2006). Belland (2014) argues that what these studies describe may not fit in the original definition of fading since simply following a pre-structured schedule does not necessarily confirm that students are being able to complete the task independently. Also, self-assessment by the students is problematic because they often cannot accurately assess their own understanding (Graesser, et al., 2011).

Also, several researchers argued that the nature and structure of scaffolding support in inquiry online learning (or with hypermedia) has diverged from the traditional, particular understanding of scaffolding (Azevedo et al., 2008; Jacobson, 2008). Indeed, in online settings, the conceptions of scaffolding include more facets of support than were envisaged in the pioneering study conducted by Wood et al. (1976). In online settings, scaffolded support could very well be in the form of software or web-based instructional tools or virtual learning objects. Web-based instructional tools are the internet-based applications or websites used by teachers as a platform to support students learning (Jumaat et al., 2014). Therefore, the concept of scaffolding has different implications in online settings because of the absence of immediate human support (McLoughlin, 2004). In this context, learners receive assistance from interaction with the computer program or web-based programme rather than from a teacher or through peer interaction. Such a relationship between the learner and the technology provides learners with opportunities to acquire skills and develop awareness of self-regulated learning. Moreover, recent studies examining the use of scaffolding in technology-mediated environments explore diverse aspects of learning including higher-order cognitive and metacognitive skills. Belland et al. (2015), for example, suggested that scaffolding can support higher-order thinking skills such as argumentation, evaluation as well as knowledge integration such as the ability to expand, revise, restructure, reconnect and reprioritize scientific concepts (M. C. Linn, 2000).

2.5.1 **Role of scaffolding in online learning**

Successful integration of technology with appropriate scaffolding for learning within the online context is a complex task. Without using a suitable pedagogical strategy, embedding technology-enhanced scaffolds may undermine rather than promote problem-solving. With direct instructions, such as what to do, and how to do it in a technology environment, learners may simply comply with directions rather than cognitively engage (Kim et al., 2011). Indeed, a previous study reports that students became dependent on these scaffolds (known as static scaffold: fixed prompts and supports) and were unable to demonstrate problem-solving skills independently once the supports were removed (Oliver et al., 2001). Therefore, a challenge remains for the researchers to determine how technology affordances can be deployed in both effective and practical ways to promote inquiry learning in online settings (Kim et al., 2011)

However, systematic student interaction with online content is a prerequisite for realizing an effective inquiry learning process (Garrison et al., 2005). The purpose of such systematic educational experience is to achieve the designated learning outcomes. Researchers have investigated the various aspects of the online learning structure and, as a result, have proposed several scaffolding strategies to support online inquiry learning. Some of the guidelines for online inquiry learning include: (a) explicit description of the structure of online inquiry tasks; (b) Integrating a planning tool that helps learners to plan their online inquiry in advance; (c) making the online inquiry process explicit to learners so that they can monitor and regulate their work; and (d) providing prompts to help learners to reflect upon and articulate their inquiry process (Quintana et al., 2004; Quintana et al., 2005). There are other forms of support in existence that scaffold learning more systematically such as WISE and ThinkerTools. In these environments, the learner is led through a sequence of steps that collectively represents the inquiry cycle. Learners can only proceed to the next step once they complete the activity that they are currently working on. This kind of process support constrains learners in their actions, preventing paths being followed that may be detrimental for their learning processes (van Joolingen et al., 2007). Another type of scaffolding is provided by WebQuest so that lesson designs using teacher-prescribed problems and teacher-supplied steps and resources are provided (F. Wang et al., 2005).

Advances in technology have unlocked the online learning environment to include hypermedia, hypertext, collaborative learning, and web-based learning environments. This challenges traditional learning design conceptions of scaffolding for educators. Therefore, a number of research studies have been conducted to formulate effective scaffolding strategies for online learning. Some of the scaffolding techniques developed over the past decade include implicit and explicit scaffolding (Hadwin et al., 2001), hard (fixed, stable, pre-set) and soft (dynamic, flexible, adaptive) scaffolding (Saye et al., 2002), and fixed and adaptive scaffolding by Jacobson et al. (2008) to promote self-regulated learning. Contemporary research on metacognitive tools has highlighted the importance of adaptive scaffolding in facilitating inquiry learning with technologies. The research done by Jacobson et al. (2008) reveals a balance between domain content knowledge and self-regulated learning processes. In another study, Azevedo (2005) suggests that adaptive scaffolding enhances student problem solving by fostering the development of mental models, and gains in declarative knowledge which facilitate the students' self-regulatory behaviour in a technology-enhanced environment.

However, research reveals little about the dynamic and holistic nature of scaffolding support in the learning context. Therefore, the aspects of how students learn or optimize technological affordances within the technology environment remain unclear (Hannafin et al., 2004; Kim et al., 2007). In practice, students often require considerable assistance to engage satisfactorily in problem-solving inquiry environments. Teachers tend to use technology scaffolds without contextualizing and integrating them into the facilitation of student problem solving (Cuban, 2001). Significantly, Kim et al. (2011), in their study, argue for the necessity of dynamic scaffolding, which is holistic, integrated, and a synergistic approach to support learners through just-in-time support and proper integration of multiple scaffolding resources such as human interventions, technologies, and sympathetic learning contexts.

One important differentiated source of scaffolding that has been studied by Hannafin et al. (1999) and Hill et al. (2001) relates to different aspects of learning in a technology-enhanced environment. They classified technology-enhanced online scaffolding into four types: conceptual, metacognitive, procedural, and strategic scaffolding. This typology of scaffolding was developed in the context of 'open learning environments' (Hannafin et al., 1999). Conceptual scaffolding guides students to consider and assists their reasoning through complex problems. Metacognitive scaffolding enables metacognitive thinking and facilitates metacognitive processes such as self-regulation, including planning, monitoring, and evaluating. Procedural scaffolding focuses on the operational, how-to features of the learning environment and provides cognitive structures to assist students in completing tasks (Sharma et al., 2007). Finally, strategic scaffolding offers guidance on how to approach learning tasks or problems (Yun Jo An et al., 2014).

Many researchers are adopting this typology of scaffolding proposed by Hannafin et al. (1999) in online and technology-mediated contexts to support student learning. For example, a study has been conducted on its potential to mediate the quality of designs and for creating large numbers of high-quality online course materials (Way et al., 2008). Yun Jo An (2010) examined the effectiveness of these four types of scaffolding in supporting students' wiki-based, ill-structured problem-solving in an online course. She found that metacognitive scaffolds facilitated students to develop problem-solving skills, to monitor and evaluate their progress, make essential changes to improve the problem-solving processes and avoid procrastination. Orrill (2002) used these scaffolding types to help describe the role of the components in learning objects in an Inquiry-based online learning environment. Haughey et al. (2005) applied these scaffold types in their review of several curriculum areas and, in the process, found the importance and presence of these scaffoldings in the curriculum. Recently, it was proposed that in a student-centred learning environment, learners can learn autonomously through metacognitive, procedural, conceptual, and strategic scaffolding (E. Lee et al., 2016).

Despite a number of studies examining diverse scaffolding tools, it has proven difficult to implement in a complex, online environment. Technology has minimized some difficulties by allowing students to access interactive materials in an unstructured and unsystematic way, but few studies have investigated scaffolding frameworks for providing students a systematic, structured and guided learning approach. Examples of frameworks that have been proposed to scaffold student learning with technologies include: scaffolding hypermedia for self-regulated learning (Azevedo, 2005); software-based metacognitive scaffolding for online inquiry (Quintana et al., 2005); a scaffolding framework to guide explanation-driven inquiry (Sandoval et al., 2004); and a framework for scaffolding problem solving in technology-enhanced learning environments (Kim et al., 2011). All of these frameworks, encompassing learning contexts where interaction with more knowledgeable (teacher, peers) others occurs, are constructed on the assumption that human support is indispensable.

Given the wide range of examples and uses of scaffolding, it is evident that this has huge potential for the realization of finely tuned, differentiated self-directed study, but to this point, it has been largely overlooked. This area of research that supports the notion of inquiry learning in the self-directed online environment requires a further commitment from the research community. Assiduous, more comprehensive investigation is required to meet the demands of formulating a framework that can be applied consistently but flexibly.

2.5.2 **Enabling inquiry learning through scaffolded learning modules**

The development of online materials needs to be conceptualized as a process of transformation rather than simply as translation of existing resources (Torrisi et al., 2000). The use of technologies does not necessarily improve the delivery of courses and learning; indeed, such an intervention needs to be redesigned and adjusted with reference to the appropriate pedagogical theories that can facilitate learners to understand science concepts in the online environment. The fundamental issue to consider when transferring and transforming the course materials to a web-based form of delivery pertains to that of the intended pedagogy (R. Mason, 1998). Continual investigation into delineating a suitable pedagogy is required based on understanding the potential of the online medium and its ever-changing nature. It is alluring perhaps to simply make course materials available in online, but researchers have eschewed this approach, recommending instead one which creates a more interactive, self-directed learning experience for students (Littlejohn et al., 1999; Petre et al., 1999).

In spite of decades of research, there are few exemplary modules incorporating online learning resources, designed to promote students' understanding of concepts that underpin successfully the learning of abstract science concepts (Lawrie et al., 2016). In their study, Lawrie et al. designed five online modules on fundamental chemistry concepts for first-year university students, which applied the current body of literature utilizing scaffolding and visual representations in this process. They found that the attitudes and perceptions of the students indicated that students mostly found these web-based modules to be useful for their learning. Garren et al. (2016) designed two scaffolded online learning modules that addressed underlying concepts and mathematical procedures related to milliequivalency and milliosmolarity. Concepts were scaffolded in three phases to improve students' conceptual understanding. Each module was accessible to students prior to the class in which that topic was covered. An in-class lecture followed the self-paced online modules. This study revealed that these scaffolded self-paced modules had a positive impact on students' results on the questions pertaining to milliequivalents. For the development of a better understanding of molecular processes, Levy (2013) designed a technology-enhanced curriculum module and made it available online, a context in which chemistry students conducted virtual experiments with dynamic molecular visualizations of solid, liquid, and gas. He found that students made progress in their level of molecular reasoning and were more able to connect intermolecular forces and phase change in their explanations. Another similar attempt was undertaken by McRae et al. (2012) in which they developed a web-based tutorial program with scaffolding and visual auxiliaries for a third-year organic chemistry class on the topic of pericyclic. This web-based learning program provided flexible delivery for the learner and the student feedback demonstrated that this was an effective approach for improving their learning outcomes.

The above mentioned literature suggests that these learning modules have enormous potential to shape the course of online learning. However, this area of research requires intensive investigation to search for a suitable scaffolding framework that works more effectively to guide students in the self-directed environment.

2.6 Pedagogy and tools of scaffolding

Many science students hold strong personal views, based on their prior knowledge and experience; the elicitation of these ideas is central to a pedagogy informed by constructivism (Driver et al., 1996). Indeed, many researchers suggest that in the constructivist learning environment it is essential to pay attention to students' initial ideas and the elicitation of those ideas (Tobin, 1990). Such an approach encourages students to seek the correct science perspective and, as a result meaningful discussion can occur (Taber, 1999). When students engage in this process of eliciting their ideas, they receive an opportunity to articulate and clarify their views and reflect critically on them (Kearney, 2002). Therefore, this process can act dynamically in facilitating the change process of their science perspectives.

In science education, among various conceptual change models, the model proposed by Posner et al. (1982) has been widely used. They proposed a framework to understand the required cognitive conditions for a learner to modify their previous conceptions or misconceptions to a more accurate understanding. According to Posner, learners must be dissatisfied with a currently held concept and feel ill at ease with their current cognitive structures. Based on these key understandings, Posner and his colleagues framed four conditions that could enable learners' conceptual change: a) The learners must be dissatisfied with their currently held concepts; b) the new conception must be intelligible; c) the new conception must appear initially plausible; and d) the new conception can be used in novel situations, outside the context that it was presented.

Previous research studies reported various instructional strategies based on conceptual change models that are successfully employed within science education (Coştu et al., 2012). Among them, the *predict, observe and explain* (POE) instructional strategy, promoted by White et al. (1992) is widely used in the field of science education. This scaffolding tool can be used efficiently to elicit student ideas. Originally this was designed as the Demonstrate, Observe and Explain (DOE) strategy (Champagne et al., 1980) to probe thinking of first-year physics students. Thereafter, it was redesigned as the *predict, observe and explain* (POE) strategy (Gunstone et al., 1981; White et al., 1992). Teachers using this strategy can offer learners an indirect instructional intervention as the means to facilitate learners in constructing their own knowledge (Treagust et al., 2014). This framework can facilitate student articulation of the ideas involved in their prediction, reasoning about their predictions, observation of the event and an explanation of any discrepancies between their predictions and observations.

There are numerous studies that have been undertaken where the POE framework in the science domain was employed. In these, the POE strategy was successfully used to probe understanding, research alternative conceptions, bring about conceptual changes, correct misconceptions, promote conceptual understanding, and so forth. Based on the POE strategy, Haysom et al. (2010), in their text, have developed a list of science activities to improve student understanding of various science concepts. In addition, researchers have also extended or modified this POE strategy based on the prevalent contextual or educational needs and found it to be effective in correcting misconceptions, promoting conceptual understanding, and for clarifying concepts. The following *table 2-2* lists some of the previous research from the last decade where the POE model was employed or was used it as the basis for formulating a modified model for instructional use.

Table 2-2: Use of POE scaffolding strategy in other studies

Reference	**Actual POE Strategy**	**Research focus**	**Topic**	**Study environment**
(Şeşen et al., 2016)	POE Predict, observe and explain	Changing attitudes, alternative conceptions	Mixtures, physical and chemical changes, acids and bases	Laboratory setup
(Treagust et al., 2014)		Promoting conceptual understanding	Redox reactions	Classroom
(Sesen, 2013)		Promoting conceptual understanding	Surface tension,	Computer-mediated tasks

			cohesion and adhesion forces	
(F. Yaman et al., 2015)		Student concept maps	Acid-base topic	Pre- and post-rest, computer-mediated tasks
(Rakkapao et al., 2014)		Promoting conceptual understanding	Force and motion	Multimedia environment: Online learning integrated with classroom
(Zacharia, 2005)		Promoting conceptual understanding	Mechanics, waves/optics, and thermal Physics	Computer simulations integrated with the course
(Hsu et al., 2011)		Scientific Knowledge construction	Light and Shadow	Computer games in classroom context
(McGregor et al., 2008)		Promoting conceptual understanding	Motion, energy flow and transformations	Simulation experiment in Lab; online discussion boards
(Kearney, 2002)		Probe science understanding	Motion	Multimedia environment
		Modified/extended POE Strategy		
(Abdullah et al., 2017; Coştu, 2008; Coştu et al., 2010, 2012)	PDEODE Predict-Discuss Explain-Observe Discuss-Explain	Correcting misconceptions; promoting conceptual understanding;	Condensation and evaporation	Classroom, pre- and post-test
(Brown et al., 2016; Brown et al., 2015; Haysom et al., 2010)	PSOE Predict, share, observe, and explain	Promoting conceptual understanding	Fluid interaction in air and water; temperature and pressure, various science concepts	Classroom, lab experiments
(Bonello et al., 2009)	PEOR Predict, explain, observe, react	Clarification of concepts and promoting affective and cognitive engagement	floating magnets: forces and fields	Classroom context

The above *table 2-2* lists some of the recent studies that adopted the POE framework in partnership with a multimedia environment, or for using the online learning materials in the classroom led environment. These studies have already demonstrated the effectiveness of the POE framework in traditional settings as well as in the technology-mediated, and in the multimedia environment. Recently, several researchers have attempted to understand students' engagement in online environments. For example, Bumbacher et al. (2017) used POE with related pedagogical strategies to investigate students productive inquiry in a manipulative environment (both physical and virtual) to understand how the manipulative environments and their affordances impact on conceptual understanding. They considered the time between experiments as a measure of how intentional learners are in their actions and what concepts they targeted during their inquiry processes to measure the quality of the research experimental process. Though the main focus of this study was to investigate the quality of students' inquiry processes, it did not consider a student's engagement during this inquiry process related to behavioural constructs such as systematic investigation and persistence. These are important criteria to measure student engagement and thus the quality of their inquiry strategies. Similarly, Brenner et al. (2017) investigated how the frequency and level of assistance provided to students interacted with their prior knowledge to affect learning in the web-based science inquiry-learning environment. They considered productive moves, clicks, total tries, elapsed time etc. to determine the level of assistance which implies students' behavioural engagement. They didn't count students' original responses during the inquiry process that may reveal their conceptual understanding or the level of their cognitive engagement. Though students' pre/post-test knowledge was assessed, that didn't translate into showing students cognitive engagement during the inquiry process. Analysing students written responses might, therefore, give an idea of students' cognitive engagement during the inquiry process and help to determine the required level of the assistance.

However, as reported earlier, the learning environment is changing rapidly with a greater employment of the online context. As such, further attention from educational researchers is required to investigate how to make the online environment viably supportive of inquiry learning. Specifically, there has been little focus on the nature of student engagement and how the embedded scaffolding facilitates students' engagement and interactions. In this regard, the following section discusses these aspects of student engagement in an online learning activity.

2.7 Importance of student engagement in online learning

Constructivism assumes that learning occurs when learners are actively engaged in an activity or course content, or through interacting with others or the environment. Constructivism, by its nature, is dependent upon engagement (K. Meyer, 2014). Therefore, engagement is a prerequisite for learning and thus is considered as central to any educational experience; it is, therefore, a primary focus in studies of online learning (Garrison et al., 2005).

Student engagement is not well understood due to the absence of a clear definition. Though researchers are agreed upon the positive impact of student engagement on learning, defining the concept is problematic due to the disagreement about what counts as student engagement (Harris, 2008). This makes it difficult to know how to measure it (Parsons et al., 2011), a difficulty residing in its multi-dimensional nature, and the overlapping phenomena between the types of student engagement (behavioural, cognitive, and emotional) and various constructs such as student on-task behaviour, attitudes, interest and values (Fredricks et al., 2004). The problematic nature creates a debate over what data is suitable for measuring student engagement (Carter et al., 2012). This is especially problematic in online learning situations.

Nevertheless, there is some agreement in the literature that engagement is a multi-faceted construct, including three key dimensions: behavioural, cognitive, and emotional engagement (Fredricks et al., 2004; Gibbs et al., 2010). Behavioural engagement generally refers to students' participation with the course content and their undertaking what is required to follow the rules and meet the educational objective delineated by an institution (Fredricks et al., 2004). Cognitive engagement refers to the effort students make in their learning processes, such as understanding complex ideas (Fredricks et al., 2004; Harris, 2008). Cognitive engagement is characterised by deep, focused and strategic thinking of students to understand the content (Louwrens et al., 2015). In the online environment, students have demonstrated evidence of deep engagement as they grow in experience with online learning. Emotional engagement refers to students' positive reaction to the contents, learning environment as well as their learning (Gibbs et al., 2010; Harris, 2008). Student interest and positive attitudes towards learning are the key elements of emotional engagement (Shu et al., 2012). Some studies demonstrate that the learning environment has a critical role in developing students' emotional engagement (D. Meyer et al., 2006). In their study, Gibbs et al. (2010) argued that students need to be behaviourally and emotionally engaged before cognitive engagement can be achieved.

Early literature in the field measured online engagement to varying degrees and in many ways (Bulger et al., 2008; Coates, 2005; Dixson, 2012). Many educational institutions are currently using the learning management system (LMS such as Blackboard, Moodle) analytics to understand learners' online engagement and activity. Markers used to capture some basic levels of qualitative engagement data include the following: the number of clicks on a web page or web content; the number of posts or reads made in a discussion forum; time spent on an individual activity; the rate of submission; the rate of completion of the activity; and so forth. Therefore, it is no surprise that early research generally conceptualised engagement as student participation, targeting, in particular, the number of web pages accessed, discussion forum posts read and made, and the completion or submission of an activity (Hrastinski, 2009; Xu, 2010). While these indicators of online participation might be considered to be signs of behavioural engagement, it is generally acknowledged that these quantitative measures are inadequate to measure the quality of student engagement. Rather, it is considered that an in-depth view of online content analysis is necessary to find evidence of student cognitive and emotional engagement (Marra et al., 2004).

Students' behavioural, cognitive and attitudinal engagement is dependent upon the online environment and the embedded support provided such as scaffolding guidance and multiple external representations. The grounds for considering sophisticated technology for providing multiple external representations like simulations reside in the appreciation that they have educational potential as well as affording learning opportunities involving active participation and engagement. Therefore, simulations provide opportunities for students to learn science concepts through engaged exploration and through the provision of innovative technology tools. Rapp (2005) described three factors that influence learning: cognitive engagement, interactivity and multimedia learning. He argued that the students' interaction with multimedia could enhance cognitive engagement.

Student engagement depends upon as well, and is influenced by, the nature of guidance provided. Adams, Paulson, et al. (2008) conducted a study with several different levels of guidance integrated into the PhET simulations within the classroom setting. Minimal guidance was found to be very useful in many of these simulations. This minimal level of guidance promoted student engagement optimally in exploring and learning. The four different levels of guidance they used were: no instruction, driving questions, gently guided, and strongly guided. Research results showed that students' learning was highly dependent on the quality of the simulations for the first two types of guidance. On the other hand, students' learning was usually independent of the simulations for the last two types of guidance. Outcomes of the research revealed that no guidance or with driving questions helped students to explore the simulations. These types of guidance supported them because it assisted them to attain physical insight into the phenomena via their own questioning. Further analysis has been undertaken in the same project and it demonstrated that the nature of guidance facilitated the amount of student engagement occurring (Adams, 2010; Podolefsky, Perkins, et al., 2010). Other studies also revealed that technology-enhanced engagement such as multi-model media objects strengthened course interactions and student engagement (H. L. Chen et al., 2009); multimedia applications improved student engagement (Schilling, 2009); LMSs (learning management systems) could influence student engagement (Coates, 2005); and, the use of WebCT improved engagement (Burgess, 2009).

In brief, it is important to consider instructional guidance and use of multiple external representations for effective student engagement in the online environment. The current study moves beyond existing research by exploring distinct types of behavioural, cognitive and attitudinal engagement in relation to the instructional guidance and multiple external representations to expand existing understanding of students' engagement in online settings. However, it is also a point of consideration that student engagement might not bring the desired learning outcomes unless students engage in a deep level approach to learning. In this direction, student approaches to learning are also a vital element to consider when designing and developing an online inquiry environment.

2.8 Student approaches to learning in online context

Marton et al. (1976) have characterized qualitative evidence of measuring students' approaches to learning as either deep or surface. They reported that when students approach learning in a deep manner, learning outcomes were qualitatively enhanced. On the other hand, when students approached learning on the surface, learning was not qualitatively enhanced; rather it involved memorizing isolated actions or reproducing what was required. These low level skills do not usually align with desirable learning outcomes. Therefore, student learning approaches and the levels of understanding remain a major concern for educators; indeed, this issue has led educators to research for highly effective strategies in the quest to assist students in the learning process (Biggs, 1987a; Case et al., 2009; Entwistle, 1991; Marton et al., 1976). However, these studies mostly consider the traditional learning context, and largely ignore the context of online environment, which is the key interest and motivation for this study.

Research reported that the educational context might play a significant role in defining the student approaches to learning as either deep or surface (Akyol et al., 2011; Sinapuelas et al., 2015). Recently, a growing body of research has investigated students' approaches to learning in online contexts (P. S. Tsai et al., 2017). One of the key challenges the researchers found in this context pertains to the self-regulation of student learning (Ekici et al., 2014). Not only it is difficult to promote for students, but also the pattern of self-regulation differs between the deep and surface learners further adding to the complexity of support. For example, Ekici et al. (2014) reported that while deep learners set learning goals for their themselves, surface learners do not, and while deep learners use time management skills to accomplish learning objectives, surface learners largely ignore this skill. This is probably due to the two different motivational orientations of deep and surface learners as reported in the traditional environment that determine their learning approaches (Biggs, 1987b; Entwistle et al., 1982). In his study S. W. Y. Lee (2013) also found that in an online context, students' approaches to learning were related to their overall motivational levels. Similarly, in a self-paced learning environment with one-to-one mentoring. motivation was found to be the important factor for managing time allocation and learning activities (Del Valle et al., 2009). Therefore, students' motivation plays a key role in regulating student learning and thus their approaches to learning in the online context.

Other research, such as Akyol et al. (2011) reported that students' cognitive presence relates to deep approaches to learning and to the learning outcomes. The focus of their study was whether online and blended collaborative communities of inquiry could promote cognitive presence that supports deep approaches to learning (higher-order learning processes) and outcomes. In addition, it references student cognitive presence while engaged in the independent learning mode which is the key concern of the current study.

In his study, Knight (2010) attempted to evaluate the different learning strategies adopted by students when accessing resources hosted in a virtual learning environment. Based on the statistics on the total number of hits on the pages and the total number of files opening (implied to reading), Knight (2010) stated that students who accessed the resources consistently adopted a deep learning approach and performed better than surface learners who accessed the online resources inconsistently. This study does not qualitatively measure the student activities, rather relied upon the statistical data of students' usage of online resources. Using an online peer assessment system, Yang et al. (2010) reported that fragmented and cohesive conceptions of learning tended to be associated with surface and deep learning approaches respectively. Similarly, in a study conducted using the online discussion platform, it was indicated that students with fragmented conceptions tended to use surface approaches while those with cohesive conceptions tended to adopt deep approaches (P. S. Tsai et al., 2017).

In brief, there is a dearth of research covering student approaches to learning in the self-directed online context where no teacher and peer support is available. Therefore, it is an important step forward to study students' learning behaviours in a self-directed study context while they are interacting independently with the online resources.

2.9 **Conclusion**

In reviewing the literature of previous studies, it became apparent that there is a need for further research to explore the use of sophisticated technology for inquiry learning in a self-directed online setting. In response to previous studies undertaken, this study has isolated three key aspects of investigation to support the theory on the positive effects of sophisticated technology in promoting students' conceptual understanding. The three areas for investigation are: i) the role of a scaffolding framework as a substitute for human support; ii) students' engagement with the online content; and iii) students' approaches to learning while studying independently in the online environment.

The current study draws on constructivist perspectives to build a scaffolding framework that underpins the investigation of the research problems. The following perspectives are articulated to support understanding of the optimum conditions for the implementation of inquiry learning in a self-directed online learning:

a) Knowledge is constructed, not discovered;

b) Individual cognitive construction (individual constructivism) and interaction with other/s (social constructivism) (in this study online environment, web-contents, simulation models, and so forth) are equally important for learning;

c) Learning is constructed based on prior experience and understanding; and

d) In relation to the scaffolding provided, approaches to assisting or scaffolds from more knowledgeable others, technology tools, cognitive tools and activities are intrinsic and necessary for promoting deep learning approaches.

Chapter 3
Research Methodology

3.1 Introduction

This chapter outlines the methodology applied to address the research questions. In addition, it provides the theoretical basis for the study and the framework that informed the development of the learning modules. First, the theoretical perspective underpinning this study is discussed. Second, the scaffolding strategy employed in the study is elucidated to establish the framework buttressing the learning modules. Third, the construct of student engagement is explored to formulate the principles for measuring student engagement in online settings. Fourth, the theoretical basis for the student learning approaches adopted in the learning modules, are explored. Finally, under the study design section, the steps of the research program undertaken are explained. The detail constructions of the different elements of the scaffolding framework has been discussed in the next chapter.

3.2 Theoretical and methodological perspective of this study

This study has enlisted constructivism as its theoretical background. The key metaphor of constructivism is that knowledge does not tell us about the world we inhabit but about our experiences in this environment. The paradigm of constructivism is based on a relativist ontology (with multiple realities) which assumes that these realities can only be known in the context of a mental framework for thinking about them (Guba, 1990). Multiple realities exist in the world of human experience and are inherently unique because they are constructed by individuals who experience the world from their own viewpoints (Cohen et al., 2013; Patton, 1990). These realities are perceived in the form of abstract constructions that are experientially located in an individual's mind (Guba et al., 1994). Based on these assumptions, it is evident that a 'single unitary reality' (Krauss, 2005) does not exist as each individual differs in experiences and value judgments. Constructivism thus encompasses the notion that a person knows or creates realities in a subjective way; that is, epistemologically, constructivism takes a subjectivist position (Guba et al., 1989). The metaphor of construction represents the subjectivist position that knowledge is constructed and adapted in the person's mind as a consequence of successive experiences and reflections (Tobin, 1990). Thus, an individual pursues the only viable path of knowledge construction comprising any action that is congruent with his or her own experiences and prior understandings (Hardy, 1997). Therefore, knowing is an adaptive process that organises one's experiential world rather than focusing on the discovery of a world that exists outside the knower's mind (Matthews, 1992).

Within the science domain, the constructivist perspective states that the purpose of science is to make sense of a world of phenomena through the pursuit of viable knowledge. Learning science can be considered as making sense of the world of phenomena through the construction of viable representations that fit within current understandings and experiences (Tobin, 1990). Driver et al. (1978) also argue that achievement in science depends upon specific abilities and the prior experiences of a person rather than being dependent upon general levels of cognitive functioning. Learners make sense of the world by interpreting new information in terms of their specific abilities and prior experience. As Jonassen (1994) described: "We learn through a continual process of constructing, interpreting, and modifying our own representations of reality based on our experiences with reality" (p. 35). Therefore, in science learning, the focus should be on students' pre-instructional ideas and knowledge. In this sense, the teacher in a constructivist environment, acts in facilitating the connections between a learner's everyday experiences and the world of science (Driver et al., 1994).

Knowledge is also constructed within the social contexts in which the learners live. Learners not only construct viable knowledge personally but also in the social contexts in which their actions are transacted (Tobin et al., 1993). Early cognitive science theories such as those emanating from the work of Piaget (1952) and others did not consider the social dimension of learning, but rather focused on individual cognitive growth. More recent access to the work of Vygotsky (1962, 1978) and others have expanded and corrected the extant views to ones that incorporate socially constructed knowledge of the learner. Solomon (1987) emphasised the co-construction of ideas through discussion between learners. She argued that the discussion between students can create a universe of discourse, a common frame of reference in which communication can take place. Therefore, in a social constructivist framework student makes sense of the world through both individual and social processes (Driver et al., 1994). Hence, from a social constructivist perspective, the construction of knowledge through the interaction between peers, located in particular contexts, is an essential part of learning. This process for the individual involves articulation, clarification, negotiation and consensus-making in the process of making sense of other students' ideas (McRobbie et al., 1997). In the technology-mediated self-directed environment, as is the case for this study, social constructivist perspectives of learning are implied with a high degree of interacting, manipulating, and controlling of the software program and web contents being employed. Williamson (1996) suggests that the more learner controlled the instructional systems are, the more generative they are; that is, they require learners to generate or construct their own knowledge.

Constructivist theories consider a naturalistic set of methodological procedures (Denzin et al., 2011). The goal of naturalistic research is to produce context-specific descriptions about the constructed multiple realities of the participants. It also incorporates the belief that the researcher, while trying to see the participant's point of view, cannot escape his own personal reality (Frey et al., 1999). Constructivist theories articulate the view that the aim of science is not the phenomena of nature but constructs that are advanced by science scholars to interpret nature (Driver et al., 1994). Science does not provide us, according to this paradigm, direct knowledge but offers a way for us to interpret events and occurrences of nature to construct true world phenomena. Indeed, scientific knowledge provides a systematic way of making sense of our observations, which are open to individual interpretations (Matthews, 1992). Nevertheless, this body of scientific knowledge is not disconnected from the knower's perspective but viewed as a set of socially exchanged understandings of the events and phenomena that constitute the experienced world (Tobin et al., 1993).

The above mentioned perspectives of science education located within the constructivist paradigm have been influential in the researcher's adopting the mixed method for this study. Constructivist researchers fundamentally rely on qualitative data collection methods and analyses, but mixed methods can also be justified within the scope of this paradigm. Alongside the qualitative data, this study has drawn upon some quantitative data because of its potential to complement the rich qualitative data collected. Data has been interpreted mainly through thematic analysis and are focused on how the scaffolding framework functions in relation to student engagement and learning approaches.

3.3 The conceptual framework of this study

This study conceptualises a pedagogical design to be used in online settings, where students are required to work independently. The following is the schematic conceptual framework that illustrates the research focus and the underpinning theoretical framework used in this study.

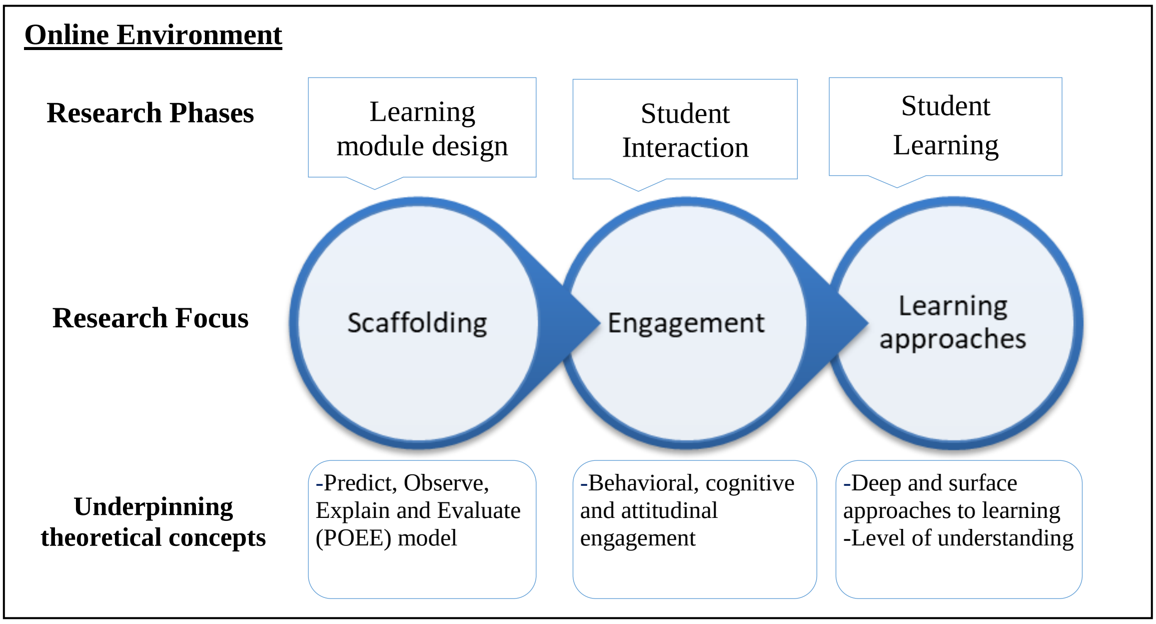


Figure 3-1: The schematic conceptual framework of the study

The following sections discuss the underlying theoretical concepts of this research that informed the research phases and research focus depicted in the above diagram. The details of the design process of the learning modules are discussed in the next chapter.

3.4 The scaffolding strategy: Predict, Observe, Explain and Evaluate (POEE)

The concept of instructional scaffolding originated in an experiment conducted in an environment influenced by constructivism (Vygotsky, 1978; Wood et al., 1976). Scaffolding is typically defined as the technique where a more knowledgeable other (MKO), frequently the teacher as facilitator, provides sufficient support for learners to succeed in solving problems that would otherwise be too difficult for them to solve independently (Wood et al., 1976). Scaffolding is also implicated in the emphasis on the development of higher order skills (Belland et al., 2008; Wood et al., 1976) and the understanding of texts and content (Azevedo, 2005; M. C. Linn, 2000). In a constructivist environment, learners construct their own ideas, an active process that potentially leads to an effective learning experience. Based on this assumption, the constructivist approach offers two potential routes for student learning. The first approach involves challenging learners to solve authentic problems in information-rich, complex settings. Through the second approach, it is suggested that knowledge can best be acquired through experience gathered in a supportive learning environment (Kirschner et al., 2006). Individual constructivism considers that knowledge is achieved through individual experiences and constructed through active learning processes (Bednar et al., 1992).

The constructivist environment is founded on the basis that students need to be empowered to control and tailor their learning. In this process, it is assumed that there is a need for autonomy while learning, to enable students to construct their own ideas and understanding in the process of being self-directed learners (Duffy et al., 1996). Therefore, approaches to learning based on constructivism emphasise the active involvement of students through interaction, collaboration, problem-solving and other forms of active participation in the constructive process. Based on constructivist perspectives, this study aimed to design two learning modules to provide students the opportunity for active participation. Furthermore, these tools were delivered to students in online settings without teacher support but were formulated to act as a 'surrogate' for direct support. Necessary scaffolding strategies were embedded in their framework so that the students could control the pace of their learning. An overarching scaffolding strategy, that is, *predict, observe, explain and evaluate* (POEE) was formulated as part of the research design to facilitate students' active participation and meaningful construction of knowledge.

POEE is the extended version of the classic research model, *predict observe explain* (POE). This strategy is considered to be a powerful pedagogical scaffolding strategy in the constructivist environment for eliciting and promoting students' science conceptions (Kearney & Treagust, 2001; White et al., 1992). It has been widely used in science learning, especially in company with technology-mediated learning (Kearney, Treagust, et al., 2001; Rakkapao et al., 2014). The POE strategy is founded on a research procedure: a prediction is proposed, explanations are given for why the prediction might be true, and then information pertinent to the phenomenon under investigation is collected through observation and then used to confirm or disconfirm the explanation (Kearney, 2003; White et al., 1992). In the traditional POE environment, students usually receive feedback when the results are discussed in the presence of their teacher (Dalziel, 2010). However, in this study, students do not have an immediate opportunity to discuss their answers or understanding with their teachers or peers as the science units were delivered online removed from direct support. In addition, as students construct knowledge through interactions with the modules, they need as well to evaluate the quality of the knowledge obtained (E. Lee et al., 2016). Therefore, an immediate and synchronous feedback feature was embedded in the learning modules. Synchronous feedback gives students the opportunity to evaluate their understanding and helps them to progress their learning. To allow for this process, this study has introduced the *evaluate (E)* phase to the original POE scaffolding strategy. Therefore, the *predict, observe, explain and evaluate* (POEE) scaffolding strategy was used as the strategic framework for the learning modules in this study.

In the *Predict* phase, this study used the notion of cognitive conflict to elicit students' initial ideas and prediction of outcomes to the problems, and then provides aids to enable them to explore and learn accurate science conceptions. The process of eliciting students' initial ideas through prediction creates an opportunity for learning (Kearney, 2004). Students' initial ideas become the basis on which they start constructing new knowledge (Bonello et al., 2009). The cognitive conflict concept originates in Piaget (1985) notion of how thinking changes and becomes more differentiated; that is, cognitive conflict leads to a state of disequilibrium between prior understandings and new phenomena. This state of disequilibrium stimulates students to modify their thinking through the processes of assimilation or accommodation, in order to attain a state of equilibrium. G. Lee et al. (2001) define cognitive conflict as a perceptual state where one notices the inconsistency between one's current cognitive knowledge and the information received in the here and now context. Therefore, cognitive conflict is the state that propels students to modify some of their existing understandings about a known topic to accord with their new found reality (Ronda, 2012). An observation and realization that their experiences are incongruent with their existing concepts appear to constitute the first step in achieving conceptual change (Limón, 2001; Posner et al., 1982). This observed incongruity creates curiosity in the students' minds, which acts as a stimulus to students' embarking on an exploratory response based on Piaget's notion of disequilibrium (Appleton et al., 1994). The current study employed several questions to precipitate cognitive conflict in students' mind before they commenced interacting with the actual learning activity in the *Observe* phase. The questions that were used to initiate the cognitive conflict are located in chapter 4: Learning module designs.

The *Predict* phase leads students to engage so a meaningful cognitive process can be transacted during the observation process (Taber, 1999). Student observation is held to be central to the POEE process in this study. The 'Observation' phase allows for the clarification of any discrepancies between the predictions and observations. It promotes effective learning through students' experiencing the relevant knowledge. If observations conflict with an earlier prediction, the reconstruction of initial thoughts is likely to reconcile the discrepancy in the process of promoting conceptual understanding (Tao et al., 1999). In the traditional POE approach, the teacher plays a significant role in the observation phase by scaffolding the activity for students, a process which helps students to reconstruct their own ideas and to engage them in higher order thinking and problem solving (Crawford, 2000). In the online self-directed mode environment, as was adopted in this study, immediate teacher support was unavailable. Therefore, instructional guidance was used, a process which potentially acts as a "surrogate" facilitator in the online self-directed environment. To explain an abstract science concept, a demonstration experiment or an actual model is often necessary for traditional settings. However, in this study, the actual model was replaced by external representations such as simulation models, videos, animations, images and texts. External representations have the potential to explain the abstract science concepts without a physical demonstration or actual experimental setups (Gilbert et al., 2009).

In the *Explain* phase, students receive the opportunity to explain their understanding of particular concepts (Gunstone et al., 1981; White et al., 1992). The current study utilized concept check questions at the end of each activity to provide students the opportunity for this purpose. Students could, however, justify their own individual ideas, understandings and justifications through their written explanations. This requirement was, however, unsupported by feedback from teachers and peers on their confusions and understandings, as occurs in traditional settings. To minimize potential confusions and discrepancies in students understanding, this current study provided synchronous feedback in the *evaluate (E)* phase.

The provision of synchronous feedback is considered to be the key element in the online environment, which facilitates students in evaluating their understanding (Zumbach et al., 2004). This approach of providing synchronous feedback in an online environment is pivotal for learning (Leibold et al., 2015). Because the feedback is embedded in the student learning space, where all learning materials and resources are available, the usefulness of feedback is maximised (Hatziapostolou et al., 2010). The feedback provided plays a crucial role in this space in the absence of immediate teacher support. The feedback was embedded in two ways in the learning modules. First, students were provided hints and useful information through ‘Hints’ and ‘Check concept’ buttons. This tool acted as internal feedback prompting students to choose suitable approaches and take remedial action, if necessary, in understanding the concepts (Butler et al., 1995). Second, detailed feedback on particular concepts that students were required to explain, was provided to correct and clarify the concepts (Keiding et al., 2014). Students obtained this feedback after finishing their written explanation of a particular concept. This support is known as external feedback and is particularly useful when students are unsure of decisions made (Lou et al., 2003). In this study, feedback was provided synchronously to students in the *evaluate* phase.

The POEE scaffolded learning modules were delivered online where students were required to engage with the self-directed mode to investigate and explore the concepts. In this mode, it was thus important to consider the level of student engagement. This study investigates the constructs available that can potentially influence student engagement in an online environment. The following section 3.6 discusses the scope of student engagement in the online learning environment.

3.5 **Student engagement**

Student engagement in self-regulated online learning settings has received little attention so far; it is thus important to investigate this critical issue considering the absence of teacher and peer support in this environment. Literature in the field has revealed that, because the meaning of student engagement is defined broadly, and it is somewhat nebulous in nature, there are contested views on its meaning, definition, and measurement (Boekaerts, 2016; Harris, 2008; Parsons et al., 2011). The method and dynamics of course delivery define the learning environment which in turn often influences the quality of student engagement (Coates, 2006). Krause et al. (2008) suggest that engagement is the quality of effort that students dedicate to educationally purposeful activities that contribute directly to their anticipated results. Bulger et al. (2008) define engagement in terms of interest, effort, motivation and time-on-task, and the period during which students are focused. Casimiro (2015) states that the nature of engagement in online learning does not differ noticeably from that delineated by key definitions of the construct as applied in traditional educational settings.

This study uses the Fredricks et al. (2004) theoretical framework of student engagement, incorporating the understandings of McGowan et al. (2010), and Barnett (2006) that distinguish student behavioural, cognitive and attitudinal engagement (the latter is also known as emotional engagement) during the learning process. This study uses the term ‘attitudinal’ as the third category of engagement in preference to ‘emotional’ engagement. Other research has used the term attitude as a construct of emotion, which supports the notion that both can be used interchangeably depending on the context (Krause et al., 2008;). Unsurprisingly, measuring students’ emotions in a distance mode is fraught with difficulties. Therefore, this study investigates attitudinal engagement through association with the students' behavioural and cognitive engagement in online settings.

In the context of online environment, this study attempts to measure several constructs of behavioural engagement such as time-on-task and the degree of effort students dedicate to the task. Time-on-task engagement is found to be an important factor for student self-regulation in the learning process (Romero Velasco & Barberà Gregori, 2011). To measure students' time-on-task engagement, their interaction time in different activities has been recorded and a standard time frame is set for each activity to define their engagement as 'high', 'low' or 'moderate'. However, the question might arise that the high time-on-task does not necessarily ensure effective student engagement. Therefore, it is important to measure students' effort level in those activities. A research study found that the degree of effort that students applied to the task is a crucial behavioural construct of effective student engagement (Krause & Coates, 2008). This study explores students 'systematic investigation' and 'persistence' on the task to measure the degree of effort student applied to the task. Fredricks et al. (2004) explain behavioural engagement as student behaviour on a learning task, which includes student persistence, effort, and their contribution towards their own learning. In this study, individual students' interactions with the simulation activities have been closely observed to record how many concepts they investigated systematically and how persistent they were during that investigation.

Fredricks et al. (2016) define cognitive engagement as the level of student investment, encompassing how thoughtful and strategic students are while learning complex ideas. In line with this definition, this study attributes student cognitive engagement based on their learning approach and the degree of logic exhibited in the process of demonstrating their understandings. Students' efforts are arbitrated as 'high' in cognitive effort when they explain the phenomena demonstrating causality, that is, why something is happening or what reasons cause that incidents. Cognitive engagement includes thoughtfulness and attention necessary to the effort required to understand concepts (McGowan et al., 2010). If students only described 'what' they are observing or experiencing, then their efforts are considered as being at the surface level.

Significantly, attitudinal engagement happens when students experience interest and enjoyment during their learning (Henrie et al., 2015). In this study, attitudinal engagement considers enthusiasm towards the task, use of resources and tools that attract the students. Students' preference and interest is a key motivational component of the learning process and influences the quality of learning in multiple ways (M. Yaman et al., 2008). Therefore, this study investigates students' preference for working with different simulation, video activities and textual instructional guidance. Specifically, this study measures students 'following the instructions' by observing their behaviour then explores what motivates them to follow, or not to follow, the instructions in the learning modules through interviews.

Research has revealed that in self-directed online learning, motivational factors are of great interest for exploring student engagement since this environment requires a high level of independence and self-direction (W. A. Zimmerman et al., 2016). Motivations for students to engage with the content in online learning environments range between extrinsic to intrinsic (Hartnett et al., 2011). For example, students completing an online activity because it is required by the teacher is an example of behavioural engagement (Fredricks et al., 2004; Gibbs et al., 2010). In their study, Deci et al. (2008) argue that this would be an example of extrinsic motivation because the students complete the activities simply because they are good students, or to avoid the negative consequences of not completing them. Therefore, students are likely to engage with online learning with extrinsic motivation to attain a reward or outcome (Glynn et al., 2011). In contrast, studies have ascertained that online learners were more intrinsically motivated than their on-campus counterparts (Shroff et al., 2008) with their intrinsic motivation being positively related to their learning performance (Cho et al., 2015). In the context of this study, potential extrinsic motivational factors are absent; therefore, it is important to understand the effects of the embedded scaffolding strategy, interactive activities and synchronous feedback on students' intrinsic motivation in the absence of extrinsic rewards.

It is to be noted that demonstrating high engagement according to different behavioural constructs does not necessarily translate to a deeper understanding of the concepts. Indeed, effective student learning approaches in tandem with particular conceptions of learning are indispensable to deep learning (Marton et al., 1993).

3.6 Students' approaches to learning

Research in education has shown that what teachers teach and what students actually learn can be remarkably different (Zirbel, 2006). This area of research was pioneered by Jean Piaget (Piaget, 1978) and Lev Vygotsky (Vygotsky, 1962, 1978). Also, student internal thinking can differ markedly during reading texts, or in understanding any concepts. Marton et al. (1976) identified a fundamental distinction in the way in which some students focussed largely on the surface meaning, and through this process endeavoured to memorize what they considered to be the key information rather than focusing on understanding the concepts. Other students, pursuing a deep approach to learning, examined the nature of a concept carefully to understand its essence. These two broad approaches to learning are known respectively as the surface and deep approaches to learning. Entwistle et al. (1979) investigated the differences between the two for learning and found that the distinction was a helpful marker for categorising students based on their learning strategies. They classified as deep thinkers those students who related the concepts to the overall goal, and, in contrast, surface thinkers who failed to do so. Marton & Säljö’s (1976) ideas on approaches to learning have been further researched and enhanced in other studies (Case et al., 2009). Further, Entwistle et al. (1979) have proposed four approaches to learning in relation to learning outcomes.

Table 3-1: Approaches to learning and outcome of learning (Entwistle et al., 1979)

Approach to learning	Outcome of learning
Deep active	Describing and justifying conclusion
Deep passive	Mentioning overall argument and conclusion
Surface active	Describing facts and components of argument
Surface passive	Mentioning facts

Marton et al. (1976) also discussed and correlated students’ approaches to learning that align with their conception of learning. Moreover, Laurillard (1978) confirmed that students’ perceptions of learning vary in different circumstances arguing that learners often switch between deep and surface approaches to learning. Another important finding was that students’ conceptions of learning are comprised of two processes: reproducing and transforming. The initial distinction was articulated by Marton et al. (1976) who, in a qualitative study examined students’ approaches to learning. Early researchers proposed that the surface approach is equated to the quantitative conception and the deep approach to the qualitative conception of learning (Entwistle, 1990; Morgan et al., 1982). Other researchers proposed that approaches to learning may be influenced by personal or contextual variables such as motivation, individual learning strategy, learner’s background (Biggs, 1987a; Duarte, 2007; Entwistle et al., 1982). However, their studies were transacted in traditional settings but the construct of a deep or surface approach to learning potentially carries the same significance for online learning. Therefore, this study enlists the traditional meaning of deep and surface approaches to learning but adopts it to the context of online learning.

In this study, student approaches to learning are categorized in terms of the level of their engagement, commitment to a task, and the strategies they employed, that is, at a surface or deep level (Biggs, 1987a; Entwistle et al., 1979; Marton et al., 1984). In line with this understanding, students’ behavioural, cognitive and attitudinal engagement and their strategies in attempting to understand science concepts are considered to measure students’ learning approaches. This study collects observational data, video records and interviews to find any evidence of student learning approaches applying several constructs including: students’ time-on-task engagement; systematic investigation; persistence; following instructions; responding to question prompts; exploring beyond the instructions; searching for new concepts; and experimenting with new ideas. Thereafter, students’ written responses to various open-ended inquiry questions, that have been embedded within the learning modules, are examined to further explore students’ approaches to learning.

3.7 Study design

This is a study grounded deeply in qualitative data collection, however to some extent quantitative data is applied to strengthen findings. Once a study combines quantitative and qualitative techniques to any degree, the study no longer is a monomethod but becomes a mixed methods design (Leech & Onwuegbuzie, 2009). Therefore, this study is methodologically aligned with mixed method approach. In this study, qualitative data has been awarded significantly higher priority than quantitative data with respect to addressing the research questions. This also gives the study a qualitative dominant status mixed methods approach (Leech & Onwuegbuzie, 2009).

The mixed methods approach is based on the premise that should include more than one research approach (Abowitz & Toole, 2009). In line with this understanding this study practices multimethod approach of collecting data such as distributing learning modules via a website, observing student activities, recording video, analysing written responses, conducting stimulated recall interviews and quantitising the data of the qualitative themes. This multimethod approach of data collection forms the basis of triangulation and corroborate or converge the results from these alternative approaches and systematically reduce potential bias inherent in any one method of data collection (Creswell, 1999).

Under the premise of a mixed methods approach, a scaffolding strategy has been framed to understand student engagement and learning approaches in an online self-directed environment. In this context, the following research questions were formulated to address the objectives of this study:

RQ1. What role can scaffolding play to facilitate student learning in online learning modules?

RQ2. What factors influence student engagement in their exploration of the learning modules?

RQ3. What learning approaches do students apply in understanding the science concepts?

The nature of the research questions demands an in-depth and thorough investigation of the phenomena to address the above mentioned educational issues. Therefore, this study employs a qualitative research design as the core of the data analysis. In this study, RQ1 involves examination of the impact of the POEE scaffolding strategy embedded in the modules along with various scaffolding supports applied in different instructional settings. This demands an in-depth examination of the students' behaviour and how it is influenced by the scaffolding strategy. Similarly, RQ2 requires the exploration of the students' behavioural, cognitive and attitudinal engagement across the learning modules. RQ3 focuses on the students' learning approaches and their conceptual understanding. All three research questions are interconnected so they need to be discussed collectively, as well as in isolation to obtain a complete picture of the overarching educational issue pertaining to the use of scaffolding.

Apart from the demands of the research questions suggesting that the data collected implicated the adoption of a qualitative approach, the nature of inquiry learning in the constructivist environment suggests that qualitative data provides the best option to gather detailed thoughts and insights into students' experiences and behaviours in the given context (Fraenkel et al., 1993). In the constructivist environment, qualitative research is employed to understand individual in-depth perceptions, to provide individual meanings in rich detail, and to vividly interpret how each participant constructs meanings and why (Creswell, 2013; Creswell et al., 2007; Krauss, 2005). Qualitative data has the potential to unearth a respondent's viewpoints through formal or informal interviews with the participants and through observations of their activities (Creswell, 2013; H. L. Wu et al., 2009). This study uses thematic analysis to identify the qualitative themes (Braun et al., 2006). The qualitative analysis potentially provides a practical enhancement to the depth and scope of the investigation because themes can be expressed verbally in narratives with supporting evidence.

In addition, to some extent, this study collects quantitative data to provide empirical evidence that is pertinent and strengthens this study's methodology (Given, 2008). This quantitative data can add precision to the findings and support the emergent themes derived from the qualitative analysis. In this process, this study utilizes a quantitising data approach to generating quantitative data, in which qualitative data is transformed into a numerical format, this is a popular approach in mixed method (Tashakkori & Teddlie, 1998). In the process of quantitising data, qualitative themes are numerically represented to fully to describe a target phenomenon (Sandelowski, 2001). This process often involves reporting effect sizes i.e., counting qualitative data (K. M. Collins, et al., 2006; Onwuegbuzie, 2003). In its simplest from, effect sizes in qualitative research represent counts of observations or themes (Onwuegbuzie & Leech, 2004). Miles and Huberman (1984) argues that the identification of categories, codes, themes are important to identify patterns more easily, and to maintain analytic integrity.

In a mixed methods research, the choice of sampling technique associated with a specific research design e.g., purposive sampling is associated with qualitative design, and random sampling is associated with quantitative design (K. M. Collins, 2010). Onwuegbuzie and Collins (2007) stated that in a mixed methods study, when the goal is not to generalize to a population but to obtain insights into a phenomenon, then the researcher purposefully selects individuals, groups, and settings that maximize understanding of the underlying phenomenon. This study selects convenience sampling which falls under the purposive sampling schemes (Onwuegbuzie & Collins, 2007). Convenience sampling choose groups or individuals that are conveniently available and willing to participate in the study.

A number of benefits that have been reported in the literature in regard to mixed methods include that researchers are able to probe further into a dataset to understand its meaning and to use one data set to verify findings stemming from the other data set (Onwuegbuzie & Teddlie, 2003). This ensures the reliability of the data that the study has generated. A diverse set of data sources like observation, video record of student activities, interview and student written responses can provide a comprehensive understanding towards addressing the research questions. The data collected from multiple sources ensure the rich description of the context and convergence of information confirms the trustworthiness and reliability of the data (Borrego, et al., 2009).

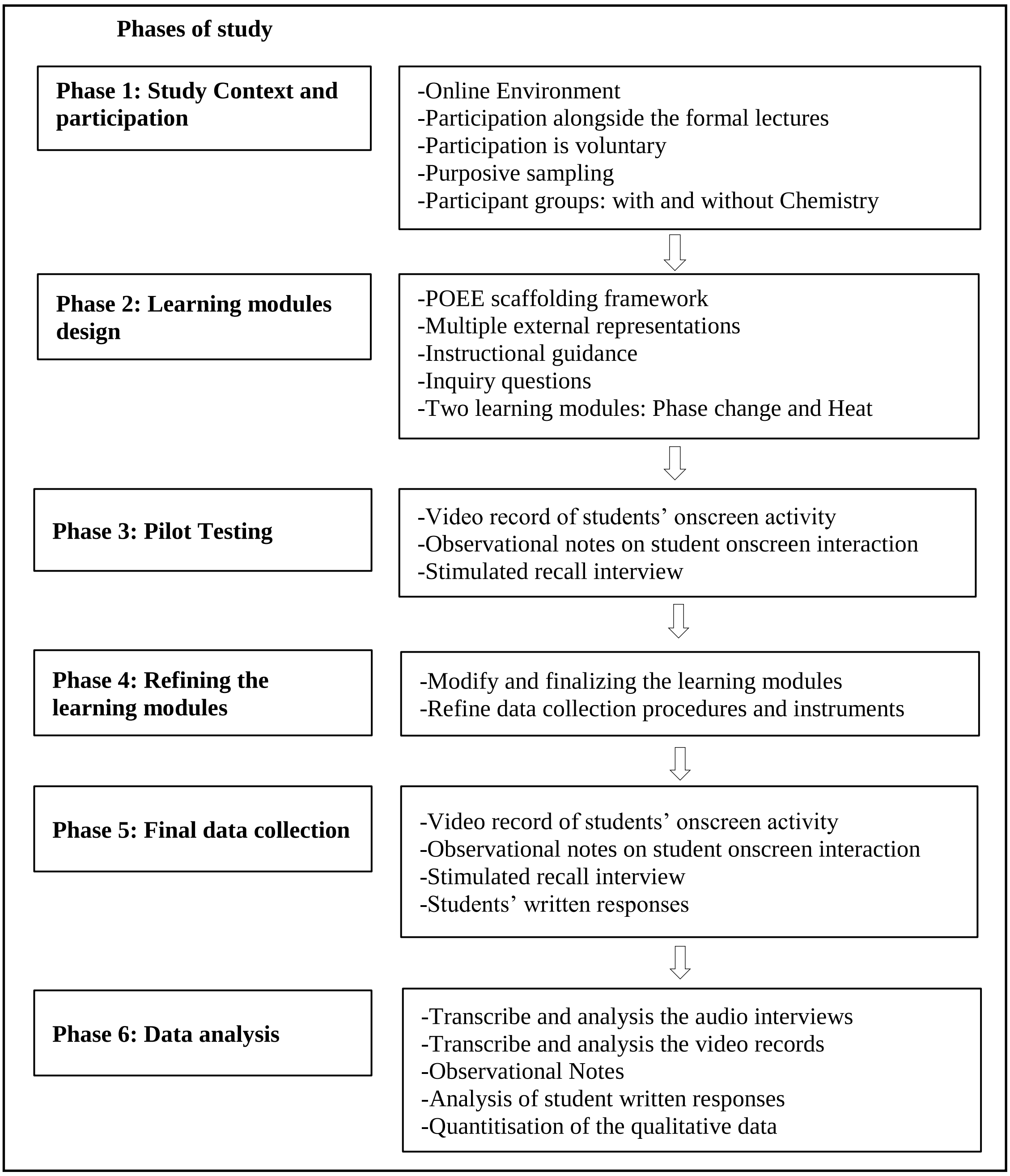


Figure 3-2: Diagrammatic model of the study design

The following sections describe the phases of the study design illustrated in the above *figure 3-2*.

3.7.1 Study context and participants

The key objective of this study was to investigate the degree of engagement experienced by a cohort of 30 first year science students' during their working on online learning modules, and the approaches they employed for understanding the abstract science concepts. The phenomena were investigated in online settings because it was difficult to address the needs of each individual in traditional classrooms with large numbers. For this purpose, a scaffolding framework was developed to design the online learning modules. These modules were deployed in the online environment. The learning modules were offered to the students alongside their regular courses. It is to be noted that the modules were not integrated into the formal curriculum; rather they were offered separately from the formal courses. However, the topics of the learning modules were the same as those they were undertaking formally. Students were required to participate and finish the learning module activities online.

To obtain a cohort from first year science students, a convenience sampling technique was utilised in this study because of their convenient accessibility. Convenience sampling is a type of non-random sampling which requires easy accessibility and availability of the participants at a given time, or their willingness to participate in the study (Dornyei, 2007). Therefore, all students enrolled in the first-year chemistry course were invited and only those who expressed interest in participating in the issue under investigation were recruited. It was considered that they were likely to be more deeply engaged and provide high quality feedback. They were invited to participate because such students have commonly revealed problems in understanding abstract science concepts at the beginning of their tertiary education (Markow et al., 1998). Therefore, the sampling technique involving the selection of only interested students from the first-year science student cohort appeared to be appropriate for this study.

This study was dependent upon a relatively small sample size of 30 students. The strength of a small sample is that it enables researchers to obtain detailed, in-depth data about the key ideas, and provides the opportunity to secure detailed experiential accounts in relation to the phenomenon under study (Creswell et al., 2007; F. Ryan et al., 2009). The participants were grouped into two streams based on their prior knowledge of chemistry. This study avoids pre-testing to group the students because of potential testing threats. Testing threat refers to changes in participants' behaviour during the actual study that occur because of what they remember from a pre-test. Researchers can control testing threat by using a control group; however, the nature of this study does not demand any control group. Therefore, grouping students based on their prior chemistry experience seems appropriate.

The first group of students had studied chemistry in secondary school while the second group had not attended any chemistry courses during their school years. The first cohort of 14 students was drawn from the course CHEM1100 studying in semester 2, 2014 while the second cohort of 16 students was drawn from the course CHEM1090 studying in semester 1, 2015. The data were collected at the University of Queensland, Australia. The following is the participant list:

Table 3-2: Participants list

Student ID [N=30]	**Learning modules**	**Background**
PHSEM201, PHSEM202, PHSEM203, PHSEM204, PHSEM205, PHSEM206, PHSEM207	Phase Change	Chemistry [N= 14] CHEM1100

HTSEM201, HTSEM202, HTSEM203, HTSEM204, HTSEM205, HTSEM206, HTSEM207	Heat	
PHSEM101, PHSEM102, PHSEM103, PHSEM104, PHSEM105, PHSEM106	Phase Change	Without Chemistry [N=16] CHEM1090
HTSEM101, HTSEM102, HTSEM103, HTSEM104, HTSEM105, HTSEM106, HTSEM107, HTSEM108, HTSEM109, HTSEM110	Heat	

All students were made aware prior to their involvement that they were going to participate in the research study and, as such, were requested to sign consent forms indicating their willingness to participate in the project.

3.7.2 **Learning modules design**

The learning modules were developed in two phases. The first phase was designed for pilot testing. Two online learning modules on *Phase change* and *Heat* were created and tested in a pilot project before the main study was conducted. The time duration to complete each module in the pilot test was approximately 30 minutes. The learning modules were developed and delivered as web content. Science simulations were central in the activities.

The second phase was the finalization of learning modules based on the findings and feedback from the pilot testing. In the main study, the duration for learning module activities was extended to 50 minutes. Some of the activities were reconstructed and modified by adding some inquiry questions, instructions, hints, and so forth. In addition, it was important to confirm the uses of the POEE strategy as the overarching scaffolding framework. Under the banner of the POEE scaffolding, various scaffolding elements were employed to support students' interactions with the learning modules. These are multiple external representations, instructional guidance, and different forms of questions, and so forth to guide inquiry during learning. The details of the design process of the learning modules are discussed in the next chapter (Chapter 4: Learning modules design). The section below discusses the findings of the pilot testing.

3.7.3 **Pilot testing**

In the pilot study, the modules were developed with various instructional guidance features ranging from offering strong or explicit support through to allowing open-ended exploration where minimal support was provided. Multiple external representations were also employed in the learning modules to help students understand the science concepts. For example, science simulations were embedded as the central learning tool alongside videos, animations and images.

To guide students' thinking in the right direction, some prompt questions were posed around the simulations activities along with some useful hints being provided. Simulations from PhET were also enlisted to construct the student's thinking in guided and less structured ways. The guided activity was developed by providing essential instructions along with relevant questions to support the simulations. The unguided activity was provided without any prior instruction and supporting questions. The students were asked to engage with the activities and explore the simulations. At the end of the activities, in both cases (MW and PhET), some concept check questions were posed to check their level of understanding.

The pilot test was undertaken in an online setting. Six volunteer participants studying at UQ were selected from the introductory chemistry courses. All the students' activities were recorded and monitored in real time. For collecting the student data, the echo360 recording system was used. Their activities were recorded in the background mode; activities undertaken on screen were monitored in real-time, through Team Viewer/ VLC software remotely. During the observation of the student activities, field notes were taken based on student responses. At the end of the activity, students were interviewed. The findings of the pilot test are summarized below:

Table 3-3: Key findings from the pilot testing

Themes	Findings
Learning Modules	Most students showed initial interest in the activity. With the progression of the learning modules, student engagement and exploration varied depending on the guidance and complexity of the contents.
Selection of the Multiple external representations	Students found the learning concept was effective when multiple external representations were available. They were especially inclined towards use of the video and animations.
Instructional settings/ guidance	Students were more comfortable with guided instruction. However, an open exploration approach needs to be further investigated as only a few participants were considered for this pilot study
Delivery	Students liked the simple and clean interface of the learning modules.
Questions used to facilitate learning and understanding	Research findings revealed that the process of writing answers to the questions posed in the modules made the value of the writing process to student learning immediately apparent. They frequently corrected their writing and checked ideas by returning to simulations.
Feedback	Having immediate available feedback also contributed significantly to the learning observed. Students made good use of and commented on feedback that provided an answer to a question, but they also made use of a "Hint" button that helped them formulate an answer.
Understanding	Overall, many of the students failed to exhibit a deep level of understanding of a concept during the learning process. The open-ended format was revealed to be less effective than the guided form of activity.
Motivation	From the interviews, there was little sign that students were intrinsically motivated by the module. Students were cautious about how interesting or fun they found the modules and were not motivated to find explanations. They suggested that they

would be more motivated by a clear linking of the module to the course so that they could find out what they had failed to understand in the lectures.

The understanding and future directions received from this pilot study were pivotal to the development of the main study. It is worth mentioning that the nature of the questions was critical to the learning process. These were constructed to meet a variety of purposes, from providing a challenge, to understanding how questions might be best formulated, thus reducing potential task ambiguity and also acting as a “hook” to elicit the interest of the students. These observations made it clear that the quality of the questions associated with the activity was a key contribution to student learning, providing scaffolding for both eliciting answers in response to a question and for providing support for students in formulating their answers. This finding is worthy of more in-depth research.

In addition, the introduction to the simulations was critical so that the students understood its purpose, how it could be managed and explored. Access to simulations and animations needs to be as streamlined as possible. Both should be embedded in the module if possible. Complexity is to be avoided in simulations because students can easily become dazzled by the detail. Mixing simulations with animations can be useful because the animations make a smaller cognitive demand on the student. These findings provided useful directions for the completion and refinement of the learning modules.

3.7.4 **Data collection**

Each individual student was invited to engage with a learning module, which they accessed on a pre-formatted computer interface in a study room in which just the student and researcher were present. Prior to their commencement, students were briefly introduced to the module, shown the simulations and how to navigate the online settings in the modules. They were then left to work independently on the module. However, their on-screen activities were monitored from a remote location (separate room) with the help of Virtual Networking Computing (VNC) software by the researcher. Drawing upon the students’ experiences, the study used the stimulated recall interview as the key tool for data collection (O'Brien, 1993). Collecting the data involved three phases, that is, video recording of students’ onscreen activity, recording of observational notes and finally undertaking the interview. The first two phases, video recording and recording of observational notes, in combination provided the groundwork for conducting the stimulated recall interview.

Table 3-4: Summary of data collection methods

Research Question	Data sources used	Research focus	Anticipated factors
RQ1. What role can scaffolding play to facilitate student learning in online learning modules?	Video records, interview and written responses	Scaffolding	Elicitation of prior knowledge, conceptual and metacognitive scaffolding, instructional guidance, inquiry questions, synchronous feedback
RQ2. What factors influence student engagement in their exploration of the learning modules?	Observational notes, Video records, interview and written responses	Behavioural engagement	Systematic investigation, persistence, time-on-task, task completion
		Cognitive Engagement	Students' strategic approach to understand the concepts, instructional guidance, prior experience, role of inquiry questions
		Attitudinal Engagement	Students' preferences, motivation to follow instructions
RQ3. What learning approaches do students apply in understanding the science concepts?	Observational Notes, Video records, interview and written responses	Approaches to learning-surface and deep level	Prior experience and domain knowledge, instructional settings, representational competence

- *Video recording:* The first step in undertaking the video recording resided in the preparation of the research subjects. All the participants were informed that their onscreen activities were going to be recorded during the session. Introductory science topics, that is, *Phase changes* and *Heat* were the focus of the learning modules designed for this study (see chapter 4 for details) and offered online to students for their engagement and exploration. While students were interacting with the online website content, their computer screen activity was monitored and recorded by Echo360 software that had been installed on the computer to record the participants' onscreen activities. Participants were required to commit to a learning module for about 50 minutes. Recorded videos were saved and held in a secure place complying with ethical approval.
- *Observational notes:* VNC, a remote access and control software was installed on both the student's and researcher's computer. This software connects the computers of the participant and the researcher. The researcher observes the participant's activities through VNC remotely from his computer enabling notes to be taken. The student's computer screen activity was cast live so that the researcher was able to monitor the progress of the investigation, noting points for discussion (See Appendix B for the examples of observation points). In addition, notes of interest were recorded during the interviews; further, the researcher composed a summary

reflecting upon each student’s interview alongside the observational notes the researcher recorded during the student interaction with the learning modules.

- *The interview:* The interview was conducted with the student immediately after the completion of the module. Each student was interviewed individually by the researcher using open-ended semi-structured questions as the basis for the eliciting of responses (see Appendix B for the examples of the questions). Stimulated-recall was a technique employed in the interview to access what the students were thinking during their interaction with the learning activity. Stimulated recall interviews help students by facilitating a reflective process (O'Brien, 1993). The aim of the interview was to investigate students’ understanding of concepts, thinking and their experience with the activity. Research indicates that in many cases students obtain the correct answer to a question but are unable to explain the reasoning for their answer. Likewise, many students who have seemingly understood concepts very well fail to respond to problems correctly in an exam situation (O'Brien, 1993). This approach to the interview potentially helps to bring to the surface gaps in students’ concepts and behaviours. The interviews in this research study commenced with questions that related directly to the students’ actions, while later questions tapped into students’ reflections upon their experiences. Some demographic data were collected about students’ earlier experience with their chemistry study and their current course enrolments. The researcher remained impartial during the interview, allowing participants to be open to their comments. During the interview, the recorded video activity was played. The following are the guidelines that were implemented during the interview (O'Brien, 1993):

    - Before the interview, check that the research subject understands the purpose of the research study.
    - Create a relaxed setting for the interview in a closed or separate room.
    - Interview each student separately, one on one.
    - The duration of the interview is about forty-five minutes.
    - Encourage the participant to pause the video and self-report on their thinking as much as possible. Encourage them to say whatever is on their mind, to not hold back any hunches, to speak as continuously as possible, to speak audibly, to not worry about speaking in complete sentences, to not over explain or justify what they have said, to control the interview as much as possible, and to elaborate as much as they like.
    - Actively listen to the participant and respect what he/she says.
    - Respond to the student's self-reporting with encouragement and invitation for further disclosure.
    - Whenever necessary, request further clarification or confirmation.
    - Avoid leading questions, making evaluative comments or being critical (e.g. "You smiled there, did you now understand how to calculate the density?'). Also, avoid leading the interview by the inappropriate use of non-verbal behaviour.
    - Initiate student self-reporting if and where necessary by asking such questions as: "What were you thinking just then?" or "What are you saying there?"

- Record all stimulated recall interviews. (p. 218)

In addition, more detailed and specific questions focusing on particular issues that were observed by the researcher were formulated during the interview.

Student written responses: Besides the dataset collected in the stimulated recall interview, this study also accessed students' individual written responses entered online to different cognitive conflict and concept check questions embedded in the learning modules (see *section 4.7, chapter 4* for details of the formulation of these questions). Students' responses were collected from the website database and the video record. These written responses on various science concepts are the key components for analysing students' learning approaches.

3.7.5 **Data analysis**

This study uses thematic analysis, the most widely used qualitative analytic method in research (Braun et al., 2006). Most researchers consider the thematic analysis to be a very useful method for capturing the details of meaning within a data set (Guest et al., 2011). Thematic analysis is a method for searching, examining, and reporting patterns and themes within a data set (Boyatzis, 1998; Braun et al., 2006). These themes are considered to be important to a specific phenomenon and pertinent to a specific research question (Braun et al., 2006). Thematic analysis can be transacted in several phases to process the data to find the meaningful patterns. This study considered the model, comprised of six phases as proposed by Braun et al. (2006) as an appropriate blueprint for this study. The following *table 3-5* delineates the six phases of thematic analysis adopted.

Table 3-5: Description of guidelines of six phases of thematic analysis (Braun et al., 2006)

Phases	**Description of the process**
Familiarizing with data	Transcribing data, reading and re-reading the data, noting down initial ideas
Generating initial codes	Coding interesting features of the data in a systematic fashion across the entire data set, organizing data relevant to each code
Searching for themes	Collating codes into potential themes, gathering all data relevant to each potential theme
Reviewing themes	Checking if the themes work in relation to the coded extracts and the entire data set, generating a thematic 'map' of the analysis
Defining and naming themes	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme
Producing the report	The final opportunity for analysis; selection of vivid, compelling extract examples; final analysis of selected extracts, relating back of the analysis to the research question and literature; producing a scholarly report of the analysis

The data derived from the recorded student activity, observational notes, interviews, students' written responses were examined and coded to find the patterns and themes across the data set that cast light on the research questions. The following six phases of thematic analysis that rely heavily on the discussion and designed by Braun et al. (2006) are described below:

Familiarisation with data: This phase requires immersion in the data for the researcher to become familiar with the depth and breadth of the content. This immersion process involves reading and re-reading data in an active way, searching for meanings and patterns. During this phase, an initial list of ideas is generated about the content of the data and what is of particular interest. Notes are made on potential ideas for coding.

Transcription of data: Transcription of the data is an important phase for becoming familiar with it and indeed is considered to be a key phase in the data analysis process (Bird, 2005; Riessman, 1993). This study adopted NVivo 10 educational software to transcribe both the audio interviews and video records with the use of the timestamps feature being employed.

Data prioritising: In this phase, ongoing discussions were transacted with the supervisors to understand what data was relevant to examine, and then, based on their advice sorting and prioritising was undertaken for further interrogation.

Generating initial codes: In this phase, the composing of initial codes from the data is completed. Codes are defined as the most basic segment of the raw data in relation to the phenomenon that can be analysed in a meaningful way (Boyatzis, 1998). In the first instance, coding is completed broadly encompassing as many potential themes/patterns as possible. Though this study employed NVivo 10 software for transcription, coding was undertaken manually. This coding phase was found to be an explicit and iterative process in which the themes and patterns were modified many times as reflected by the data, and as ideas emerged through the process of coding. Codes become the foundation for developing the themes.

Searching for themes: After initial coding and collating of the data, this phase involves re-focusing the analysis at the broader level of themes. It involves categorization of the different codes into potential themes and the collation of all the related data within the identified themes. This process precipitates the combining of codes to form key themes. The coding process helps to identify themes and sub-themes and patterns that have emerged from the coded data. As this study focuses on abstract *Phase change* and *Heat* science concepts, themes emerged from the scientific vocabulary used by the students in their responses, the issues they discussed in the interviews and from their interactions and behaviours while engaged with the learning modules. Other factors such as the frequency of occurrence of some assumptions of knowledge under certain conditions and factors were considered as significant in contributing to clarity in the construction of themes.

Reviewing themes: Once the themes emerge, this phase involves the refinement of these. During this phase, it becomes clear that some themes, as categorised as key themes, need to be discarded because there is insufficient data to support them, or the data are too scattered to establish them as key themes. Some themes are merged into each other and some themes might need to be refined by separating sub-themes that seem sufficiently significant to be promoted to themes.

Finalize theme names: This stage identifies the essence of what each theme is about and determines what aspect of the data each theme captures. The researcher defines and names each theme, explains and illustrates the themes with evidence from the original text to make its meaning clear to the reader. A detailed analysis of each theme is completed in this phase. A challenge is to ensure at this stage that the derived themes coalesce with the broader story of the study, and, in doing so, answer the research questions.

Reporting the results: This final phase involves unifying the analytic narrative and data extracts and contextualising the analysis in relation to the extant literature. It provides a concise, coherent, logical, non-repetitive and interesting account of the story of the data within and across themes. Evidence, such as examples of student written responses, quotations from the interviews are provided to support the story. The findings are discussed within an analytic narrative that compellingly illustrates themes with valid arguments in relation to the research questions being formulated.

In addition to the inductive approach as mentioned above, this study, to some extent, considers the theory driven approach (Boyatzis, 1998). For example, this study considers several constructs of student engagement, emerging from the literature as discussed in sections 3.5 and 3.6, and applies them as key indicators while searching for the themes from the data. These constructs of student engagement worked as a means of organising data for subsequent interpretation. In this process, a search for what occurs and then formulates the subthemes that would support this theory. The anticipated meaning of the expected results of the analysis determines the wording of the themes emerges from the theorist’s construction of the meaning or the expression of the elements of the theory (Fereday & Muir-Cochrane, 2006).

3.8 **Trustworthiness, reliability, validity**

Trustworthiness refers to establishing the process of reliability and validity for the study (Guba, 1981). The validity of a study ensures that appropriate research methods have been used and the results of the study have been inferred correctly (Kirk et al., 1986). Continual consultation with the supervisors and feedback from the panel have ensured that suitable research methods have been employed. In addition, by disseminating findings to the research community and the acceptance of results in peer-reviewed papers have also confirmed the validity of the study. Furthermore, some of the results and findings of this study have been presented to the wider research community at different international conferences where the researcher has accepted every opportunity to receive feedback from the research community. A portion of the findings of this study already has been accepted, presented and published in a peer-reviewed conference proceeding.

Validity also implies how useful and meaningful the research findings are to the intended community (Guba, 1981; Kvale, 1996). In this regard, the researcher has received positive feedback with some suggestions being offered from participants at different conferences where the findings have been presented. As well, the details of the findings and how they might contribute to educators in the area of online learning module design have been presented in the discussion and conclusion sections of this study. Finally, the validity of the results has been checked by comparing the findings of the current study to see if they are plausible in the light of the findings extracted from earlier related studies,

Reliability refers to the replication of the findings which suggests that if the same research problem were to be investigated with the identical research method, the results would be replicated with quality and consistency in data interpretations (Guba, 1981; Kvale, 1996). A rigorously selected methodological approach to data collection and analysis should ensure this reliability (Kvale, 1996). It was discussed earlier that an appropriate methodology has been employed in this study, an outcome reached through discussions with the supervisory team. In addition, the literature review ensures that the methods used in this study are a product of a constructivist environment. Reliability can be realized through constructive criticism too (Guba, 1981). The supervisory teams, panel members, and the wider research community helped to establish reliability for this study. For example, to ensure reliability, all the steps involved in designing the methodological procedure, learning module design, data collection and data analysis stages were discussed with the supervisory team. These ongoing discussions have confirmed that the emergent set of themes is reliable for interpreting the students' engagement and learning approaches in online settings. Further, the reliability of the data is enhanced by the convergence of findings from multiple sources, that is, the researcher's observational notes, interviews, video records, and students' written responses. As the data were collected from multiple sources, the information converging from the different sources confirms the validity and reliability of the data.

In part, the dependability of the data can be attained through the development and implementation of a systematic design of data coding (Miles et al., 2013). Dependability implies the consistency of measurement (R. Linn et al., 2008). Systematic data analysis in this study, undertaken through the well-founded thematic analysis procedure also increases the reliability of this study.

3.9 Ethical clearance

The data for the pilot test was collected in 2013 under the banner of a project run by the Department of Chemistry and Molecular Biosciences, at the University of Queensland (UQ). This project was approved under the ethics no 2013000045. The final study was approved under the ethics no 14025 from the School of Education, UQ. For the final study, a separate group of students was invited to participate in this research project. The participants were expected to be aged 18 or above. Some students, especially those in the second group in semester 1 from Chem1090, 2015 may not have been being aged 18 exactly; however, all selected students were sufficiently mature to understand the nature of the relevant information and to give informed consent. It was verified before the study was undertaken that this study did not impinge on ethical issues pertaining to other cultural or ethnic groups in Australia. In particular, the researcher was aware of the potential participation of indigenous students. Although Indigenous Australia is not the focus of this research, given that Indigenous Australians comprise 2.5% of general population, some participation was possible. For advice on this issue, the researcher consulted with Associate Professor Dr. Elizabeth Mackinlay, an indigenous education educator located at the School of Education, UQ. The researcher was also aware of the Aboriginal and Torres Strait Islander Studies Unit at UQ, as a source for providing guidance and advice on research practice involving Indigenous Australians. The AIATSIS guidelines for ethical research with Indigenous Australia (http://www.aiatsis.gov.au/research/ethics/) were also considered in this respect.

Students who participated voluntarily in the pilot test and in the main study were all first-year undergraduate students studying at UQ. Students were invited to be volunteers in the project. The consent forms and instructions were sent to the participants' email addresses prior to the activity. Before the activity was undertaken, the signed consent form was returned by a participant. The data collected in the pilot test and the main study have been used only for the intended research purposes. Students' names or any information related to the students' identity were coded and stored securely. This information, it has been stipulated, is not to be used elsewhere.

3.10 **Conclusion**

To summarize, this study adopted a constructivist paradigm of research with a relativist ontology and a subjectivist epistemological approach. In addition, it enlisted an interpretive, naturalistic methodology to investigate how science students engaged and behaved in response to the scaffolded learning activities in the online self-directed environment. Qualitative data approaches were used under the banner of an interpretive methodology to provide insights into the students' interaction with the online contents. A constructivist learning theory acknowledges that students build their science views based on their prior knowledge and experiences. Therefore, this study provided the POEE scaffolding strategy to act as an effective instrument for eliciting students' initial ideas and to guide them through the inquiry learning process which was intrinsic to the successful completion of the learning modules.

Chapter 4
Learning Modules Design

4.1 Introduction

This chapter explains the design of the learning modules and in particular the modification of the POE to add the *evaluation (E)* phase in the online self-directed environment. In addition, the theoretical basis and development of the scaffolding elements and how these have been employed in the learning modules are discussed; how, for example, the design rationale, external representations, instructional guidance, and inquiry questions have been employed in the learning modules. In addition, this chapter explicates, with examples being provided, the formulation of and justification for different activities being incorporated into the learning modules.

4.2 The Learning modules

Two learning modules for introductory science concepts of *Phase change* and *Heat* were designed for this study. There are several concepts in phase change and heat that generally are poorly developed in students' thinking, a legacy perhaps of ineffective teaching and learning in these areas during secondary school (Alwan, 2011; Driver et al., 1978; Nottis et al., 2010; Prince et al., 2012; Shepherd et al., 1982). In response, this study aimed to investigate student engagement and learning of these two topics in online settings. The desired learning outcomes that the student should be able to achieve were provided at the beginning of each module. The desired learning outcomes are shown in the following table-

Table 4-1: Learning objectives for the Phase change and Heat module development

Learning objectives (LO) for Phase change module	**Learning objectives (LO) for Heat module**
LO1: Understand the different classes of strong and weak intermolecular interactions LO2: Understand how intermolecular forces relate to the physical properties of a substance, including phase change LO3: Identify the molecular structure of the solid, liquid and gaseous forms of water. LO4: Explain the properties of solid, liquid and gaseous water in terms of their molecular structure	LO1: Understand the principles of heat transfer LO2: Consolidate understanding of the differences between temperature, heat and thermal energy LO3: Grasp the relationships between heat/thermal energy, particle kinetic energy and temperature LO4: Predict, at a basic level, the efficiency of an object to conduct heat, based on the nature of the material and its shape LO5: Recognise that thermal expansion is one of the physical manifestations of heat transfer LO6: Understand the physical mechanism of thermal expansion

Both learning modules are comprised of a number of concepts that the students are required to explore. The following table lists the key concepts in each module.

Table 4-2: Key science concepts used to develop the learning modules

Learning modules	Key concepts (KCs)
Phase Change	*KC1*. Intermolecular attractions; *KC2*. Polar and non-polar and dipole-dipole and London-dispersion forces; *KC3*. Hydrogen bonding in water; *KC4*. Evaporation process; *KC5*. Molecules structure and behaviour of water in solid, liquid and gaseous phases
Heat	*KC6*. Difference between heat and temperature; *KC7*. Heat transfer process; *KC8*. Thermal equilibrium; *KC9*. Heat conduction; *KC10*. Thermal expansion

Each learning module comprises a number of POEE activities that students needed to engage with and explore to understand the above-listed concepts across the two learning modules. The following two schematic representations illustrate the complete structure of the two learning modules used in this study.

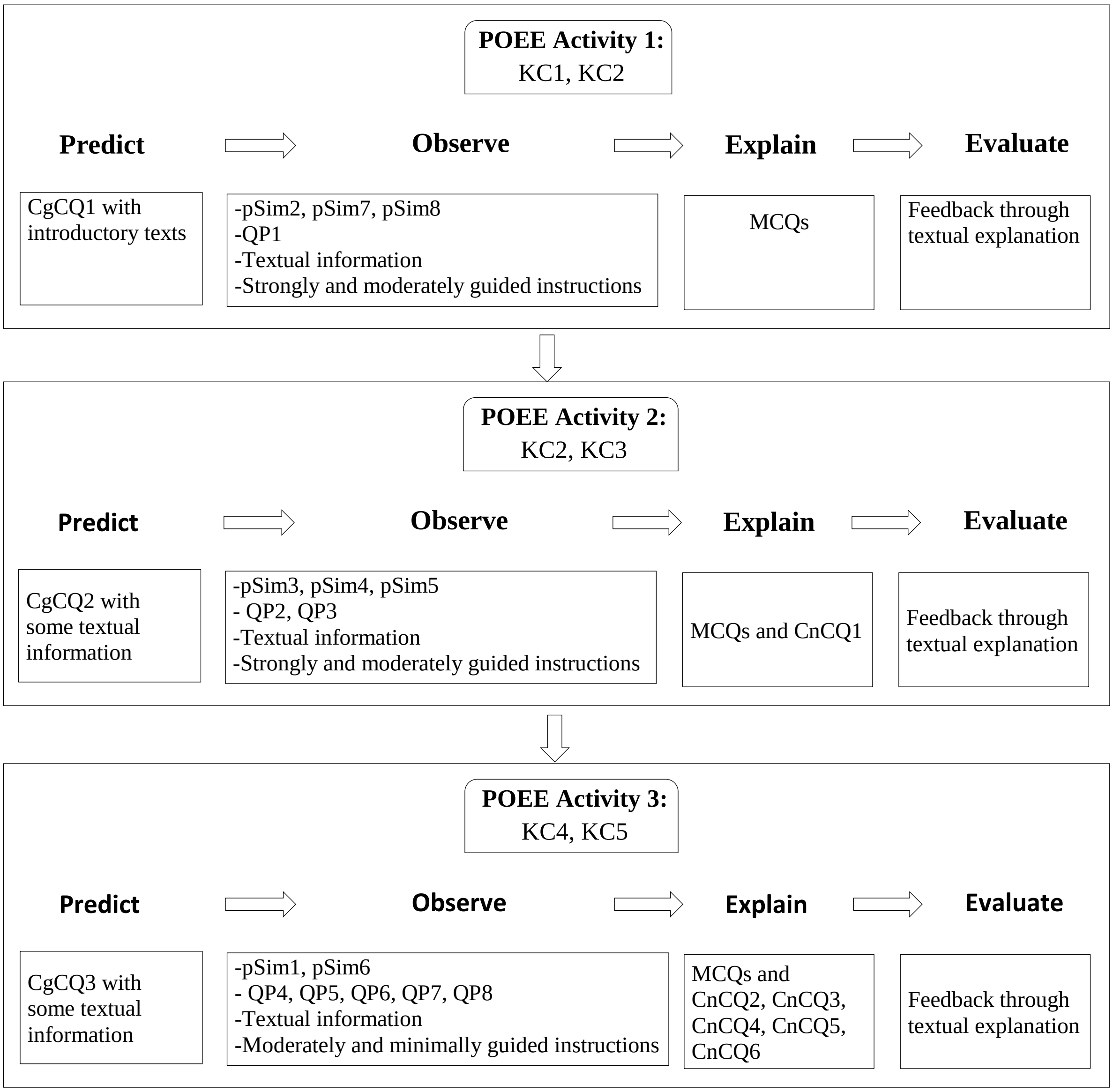


Figure 4-1: Flow diagram of student activity in Phase Change module

The above diagram represents three POEE activities that required the students to explore and investigate to understand the key concepts listed in the *table 4-2*. The following diagram represents the three POEE activities in the Heat module.

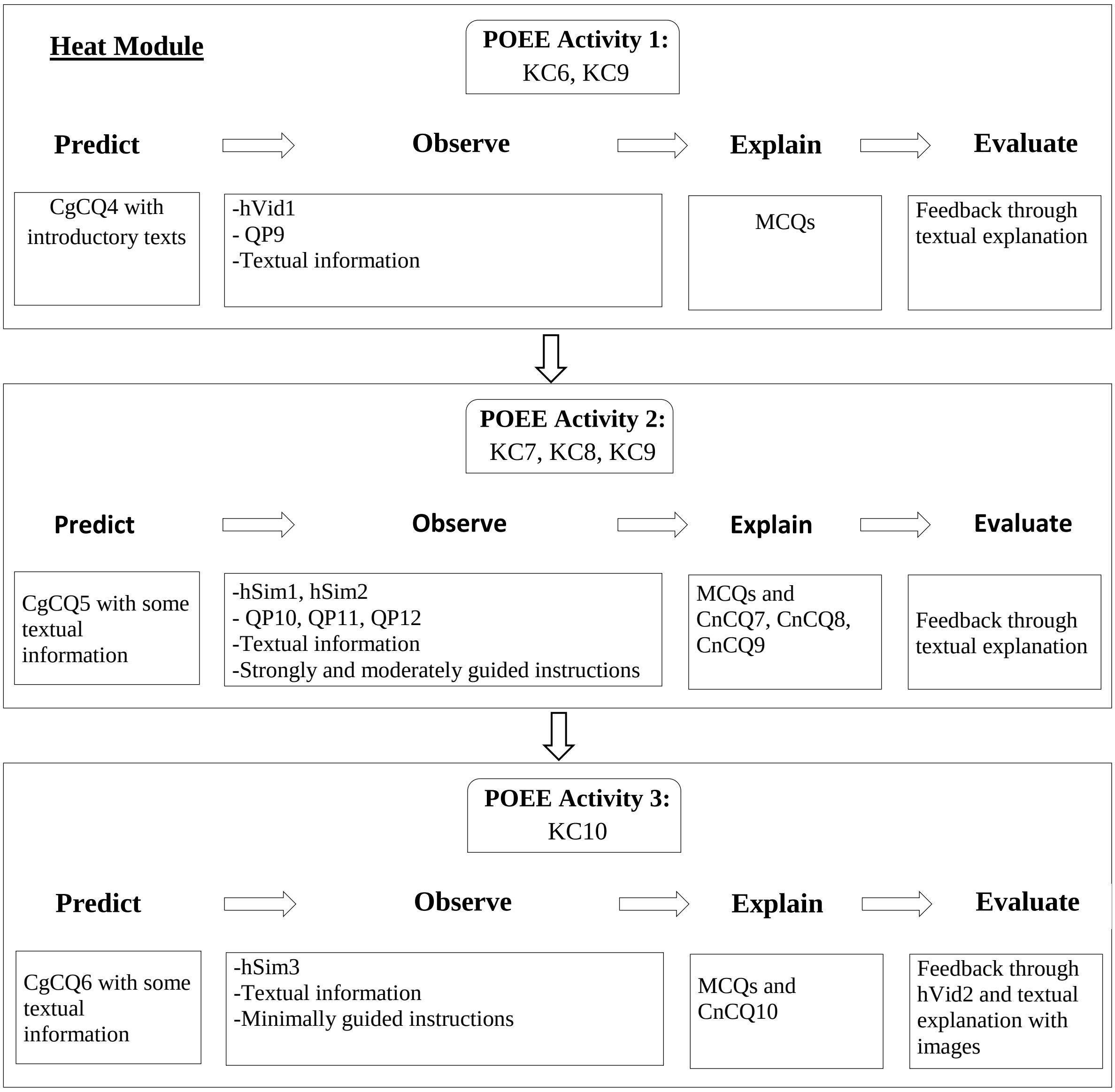


Figure 4-2: A schematic illustration of students' activity flow in the Heat module

4.3 The POEE scaffolding strategy

In this study, an extended generic *predict, observe, explain and evaluate* (POEE) pedagogical strategy has been employed to scaffold students' independent study. The intention was to prompt students' initial ideas, motivate them to explore the concept and embark on investigations (White et al., 1992). Thereafter, students' understanding was modified by giving them synchronous feedback on the related concepts. The following schematic diagram in figure 4-3 illustrates the intended flow of progress in students' thinking and their activities guided by the POEE model:

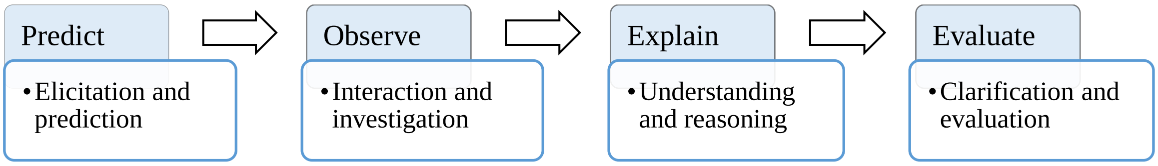


Figure 4-3: The schematic representation of student activities guided by POEE model

During the activity, it was expected that the POEE framework would guide students in the learning and engagement process. Each learning module comprises a number of POEE activities. For example, both the *Phase Change* and *Heat* learning modules have three POEE activities. The following table 4.3 shows the expected students' behaviour in each POEE phase.

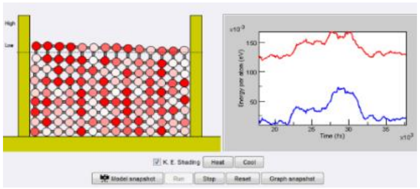
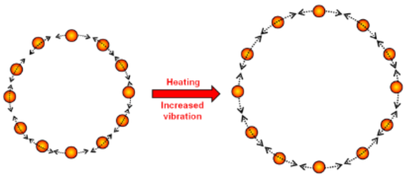
Table 4-3: POEE and expected students' behaviour

POEE	**Expected students' behaviour**
Predict	Students predict the possible answer. The challenge students face in this phase will elicit and conceptualise their thinking in a specific direction. Gunstone (1995) recommends that students write their predictions with reasons to increase their level of commitment to the learning activity. This process encourages the formation of links between new and old concepts.
Observe	Students interact with the activities and contrast the outcome with their prediction. Self-regulation can take place during the exploration which brings more self-exploration of the given concepts and initiates a meaningful cognitive process and knowledge construction.
Explain	Students justify individual ideas with reasoning. This conceptually scaffolds a student's cognitive processing of the given concepts to help the process of deep learning. At the same time, it can support reconstructions and reformulations of thoughts and function as metacognitive scaffolding.
Evaluate	Students receive feedback so, as a result, clarifies and evaluates understanding. This evaluation helps the student to participate in meaningful knowledge construction (E. Lee et al., 2016) and facilitate competencies and understanding of the given problem (Hyland, 2000).

The above table indicates the aim for the POEE model on student behaviour. The POEE model works as the umbrella framework in the learning modules. To better understand how POEE model employed in the learning module, an example is shown below. The following POEE activity is taken from the Heat module (POEE activity 3, figure 4.2). It illustrates the different phases of the POEE model and the subsequent scaffolding supports provided under each of these phases.

Table 4-4: Example of a POEE activity, extracted from Heat module

POEE Task	**Representations**	**Scaffolding Elements**
Predict (P) When you heat a substance, the rise in temperature is not the only thing that occurs on the atomic scale. There are other important changes that can arise from the transfer of heat energy. Think about the following question and explain your understanding in the text box. *Railway lines can buckle in very hot weather. Explain how this might occur in molecular terms.*	 Figure 4-4: Buckled rail lines, Representations of an actual object	-Cognitive conflict questions: CgCQ6 -External representations: image and text

<u>Observe (O)</u> The following simulation shows that a solid responds to heat input by increasing its volume due to increased atomic vibrations. This is thermal expansion. *Click here* to go to the Molecular Workbench simulation entitled: Heat and Temperature: An energy view of heating (extract from page 8). Once you finish the activity, return to this page and do the following concept check activity.	 Figure 4-5: Molecules vibration in solid, representation at the molecular level, hSim3)	-External representations: hSim3 -textual instructions -Instructional guidance is minimal
<u>Explain (E)</u> *The iron plate pictured here has a hole cut in its centre. What will happen to the hole when the plate is heated? Explain in molecular terms with reasoning.*	 Figure 4-6: Hole in iron plate, representation of an actual object	-Concept check questions: CnCQ10 -External representations: image and text
<u>Evaluate (E)</u> Students received synchronous feedback ***Feedback 1:*** First of all, we need to recognise what is occurring on a molecular/atomic level, when the iron is heated. -the iron atoms vibrate more due to the increase in heat energy -each atom takes up more space Consequently, on average each atom is further apart from its neighbours. This results in "thermal expansion" in the material being heated. Here, the iron plate will expand. It is relatively simple to rationalise that the circumference of the outside of the plate has expanded, but this is not as simple when we consider the inner hole. Imagine the atoms that line the edge of the inner hole (effectively a circle of atoms – see the diagram below). If the distance between them increases, then the circle becomes bigger. In effect, the hole increases in size. ***Feedback 2:*** Watch the video to see a classic demonstration of this concept using a brass ball and ring.	<u>Feedback 1</u>  Figure 4-7: Thermal expansion, representation at the molecular <u>Feedback 2</u>  Figure 4-8: Video demonstration on expanding inner hole of an iron (Source: YouTube, <u>https://www.youtube.com/watch?v=V0ETKRz2UCA</u>)	-Synchronous feedback -External representations: Images with textual explanation and video demonstration

Additionally, this study employs the conceptual, procedural, and metacognitive scaffolding strategy suggested by Hannafin et al. (1999) through multiple external representations, instructional guidance, inquiry questions which are discussed in the following sections.

4.4 Scaffolding supports: Conceptual, procedural, and metacognitive

The study has been constructed to study the benefits of providing conceptual, procedural, and metacognitive scaffolding support in an online setting to help students to engage and learn effectively. The potential benefits of structuring learning through the embedding of various scaffolding features have increasingly attracted the attention of researchers in recent years (Ding et al., 2011; Jumaat et al., 2014; Pan et al., 2012). The use of various scaffolding strategies potentially assists students in bridging the gap between what they can do on their own and what they can do with the help of a more capable other (Hannafin et al., 1999; Wood et al., 1976). Moreover, the scaffolding supports the student in deciding what to consider or to prioritize, that is, what is valuable for their learning (Hannafin et al., 1999).

First, conceptual scaffolding helps students to identify key knowledge and assists them in connecting and organizing knowledge related to a problem (Pan et al., 2012). It can align students' thinking with the underlying concepts and helps them to solve the subsequent problem requiring the synthesis of information (Ding et al., 2011). Conceptual scaffolding can be provided in various ways, in particular through visual representations of relationships among concepts and by providing information and hints (Hannafin et al., 1999). Second, procedural scaffolding assists students in understanding how to use the available resources and tools. It orients students to the features and functions of the learning environment (Hannafin et al., 1999) and offers a cognitive structure to help students to solve the problems (Sharma et al., 2007). In the context of science learning, procedural scaffolding is comprised of instructions on what to do and how to solve the conceptual science problems (Davis, 2000). This scaffolding reduces learners' cognitive load by providing detailed instructions and guiding them in key aspects of the task (E. Lee et al., 2016). Finally, metacognitive scaffolding supports students in processing the underlying ideas related to the learning problem (E. Lee et al., 2016). It provides guidance in how to think about the learning problem (Hannafin et al., 1999). Such an approach can improve student awareness of what they are learning (metacognitive knowledge) and how to regulate their cognitive processes (metacognitive regulation) for effective learning (García Rodicio et al., 2013). This study includes the provision of these scaffolding supports in each phase of the POEE model. The following table 4.5 illustrates how students receive this support in different phases of the POEE.

Table 4-5: Scaffolding supports provided across the phases of POEE

Scaffolding Phase	**Scaffolding supports**	**Scaffolding elements used**			
		Representations	**Instructional guidance**	**Inquiry questions**	**Hints and feedback**
Predict	Conceptual and metacognitive scaffolding: Provide cognitive direction in the learning process and elicit higher order thinking	textual information, and images	NA	Cognitive conflict questions	NA
Observe	Conceptual, procedural, and metacognitive scaffolding:	Texts, simulations, videos,	Strong, moderate and open/minimal	Question prompts	Hints, highlighted words and

	-Build in affordances to provide cognitive and intuitive direction in the learning process - Elicit higher order thinking - Promote self-regulation - Provide instructional direction - Offer familiarization of task - Provide directions to use and utilise the resources	animations and images	guided activities		‘check concept’ activities
Explain	Conceptual and metacognitive scaffolding: Test student knowledge; ask them to demonstrate their level of understanding in the given problem situation based on their prior experience and interaction in the *Observe* phase.	Text and images	NA	Concept check questions, MCQ and confidence check questions	NA
Evaluate	Metacognitive scaffolding: Provide the evaluative or corrective information about student responses.	Texts, images and videos	NA	NA	Synchronous feedback

Simulations, videos, animations, images, instructional guidance, questions, and textual information were used as conceptual scaffolding to support students’ activities. These scaffolding elements, used in both traditional and online learning environments, can be classified as multiple external representations. Further, these multiple external representations utilized in the modules increased the likelihood that the conceptual, procedural and metacognitive supports would be influential during an activity (Danilenko, 2010).

4.5 Multiple External Representations (MERs)

This study has adopted a range of external representations, acknowledged in the literature review, which have notable benefits. For example, research findings demonstrated that the use of multiple external representations (MERs) facilitated learning in the multimedia environment (Mayer, 2002; Moreno et al., 2004). Students can learn more deeply from the multiple visual representations of the information than they might from the traditional modes of communication involving verbalization (Mayer, 2003). Integration of multiple representations allows students to comprehend complex scientific processes and apply their existing knowledge to new situations (Mayer, 1999). It also helps learners to construct conceptual knowledge (Ainsworth, 2006; Schwonke et al., 2009), and create dynamic mental models promoting deep knowledge construction (Hegarty, 2004; Schank et al., 2002). In science, MERs can provide information in more than one format and can as well support the process of developing representational competence (Barrett et al., 2015; H. K. Wu et al., 2012). Due to the ability to represent the complex phenomena of scientific concepts in multiple formats, it has been widely used in the science domain (Rau et al., 2015). In this regard, Johnstone (1993), Gilbert (2008) and Gilbert et al. (2016) classified and discussed three representational levels in which the visualisation operates functionally, that is, at the macroscopic, sub-microscopic and symbolic levels (Johnstone, 1991). This study used these representational levels to facilitate students to understand the phenomena of abstract science concepts in the learning modules. The following *table 4-6* illustrates the types of MERs used in this study.

Table 4-6: Types of MERs used in this study

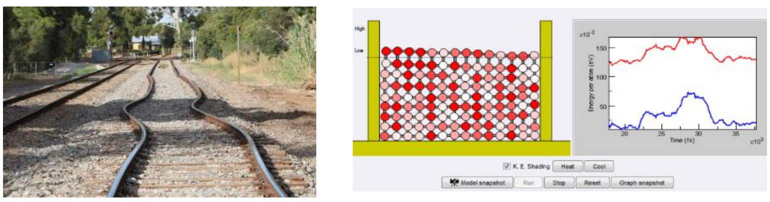
Multiple External Representations (MERs)	Visual nature	Examples of representations used in this study
Symbolic representations	Symbolic	Texts (questions, textual instructions, textual information, hints, highlighted words)
Macroscopic and sub-microscopic representations	Static	Images, photos, diagrams
	Dynamic	Animations, videos
	Interactive	Simulations

The sub-microscopic representations of the abstract science concepts phenomena played the key role in this study alongside the macroscopic and symbolic representations. To understand how these representational levels work, the concept of thermal expansion embedded in the *Heat* module is considered here (see the following figure 4.9). Thermal expansion is an abstract science concept and requires molecular level representations of the phenomena to help students to understand the process. The following figure represents the three representational levels of this concept.

Macroscopic representation

Sub-microscopic representation

Symbolic representation



The simulation model shows that a solid responds to heat input by increasing its volume due to increased atomic vibrations. This is thermal expansion. The buckled rail lines are an example.

Figure 4-9: Examples of three different representational levels (extracted from *Heat* module)

As shown in the above figure, this study uses sophisticated technology notably simulations, videos and animations to represent this sub-microscopic world of abstract science concepts. Sub-microscopic representations of an atom are important for understanding its spatial arrangement in molecules (M. Cheng et al., 2009). Indeed, M. Cheng et al. (2009) argued that the properties of molecules depend not only on their atomic composition but also on the spatial arrangement of those atoms in the molecules. Therefore, it is important to "see" the sub-microscopic representations to understand the abstract science concepts. The above figure 4-9 first displays the concept at the *macroscopic* level. The buckled rail lines represent the thermal expansion of the rail lines, which is the observable phenomenon. The second occurs at the *sub-microscopic* level, a representation of those components that are supposed to cause the properties being displayed at the macroscopic level. The example illustrates atoms and molecules in hot and vibrating states that cause the thermal expansion. The third is the *symbolic* level where the abstractions are used to depict the objects at the sub-microscopic level. An example is the textual information and instructions given in the problem scenario. Apart from this example of thermal expansion, this study designed a number of abstract science concepts activities drawn from the chemistry domain using the different representational levels suggested by Johnstone (1993), and Gilbert (2008). The following are the list of external representations resources used in this study.

Table 4-7: MERs used in Phase Change module

MERs	Concepts to investigate	Source	Learning objectives
	Interactive representations (Sub-microscopic)		
pSim1 (simulation): States of Matter: Basics	Molecules structure in three different phases; relationship between heat, temperature, volume and pressure and their effect on three different states of water	PhET	LO2, LO3, LO4
pSim2 (simulation): Polar and non-polar liquid	Intermolecular attractions in liquid; polar and non-polar attractions	MolecularWorkbench	LO1, LO2
pSim3 (simulation): Oil and water molecules	Oil and water molecules structure and their arrangement in the liquid	MolecularWorkbench	LO1, LO2
pSim4 (simulation): Single water molecule, ice and liquid water	Spatial structure of liquid water and ice	.PDB files for JMOL view	LO3
pSim5 (simulation): Hydrogen Bonds	Hydrogen bonds in water	MolecularWorkbench	LO3, LO4
pSim6 (simulation): Evaporation model	Molecules evaporation process	MolecularWorkbench	LO4
pSim7 (simulation): Polar and non-polar molecules and their attractions	Dipole-dipole and London-dispersion attractions	MolecularWorkbench	LO1, LO2
pSim8 (simulation): Dipole-dipole and London-dispersion attractions	Dipole-dipole and London-dispersion attractions	Chemsite	LO1, LO2

Dynamic representations (Sub-microscopic)			
pVid1 (Video): Structure of solid, liquid and gaseous state		Canadian-Museum-of-Nature	LO2, LO3, LO4
Static Representations (Macroscopic and sub-microscopic)			
Images and diagrams	Understanding the concept from both actual and molecular level perspectives	IAMMIC-project (2013) and open source materials from the internet	LO1, LO2, LO3, LO4
Symbolic representations			
Textual information and instructions Cognitive Conflict Questions (CgCQs) Concept Check Questions (CnCQs) Question Prompts (QPs) Multiple choice questions Synchronous feedback		Some CgCQs and CnCQs have been adopted from IAMMIC-project	LO1, LO2, LO3, LO4

Table 4-8: MERs used in Heat module

MERs	Concepts to investigate	Source	Learning Objectives
Interactive representations (Sub-microscopic)			
hSim1 (simulation): Mixing hot and cold chamber	Heat transfer process at molecular level	MolecularWorkbench	LO1, LO3
hSim2 (simulation): Heat and temperature: Heat conduction (MW) (Includes taking snapshots and its explanation)	Heat conduction process; the effectiveness of heat conduction of different mediums; thermal equilibrium	MolecularWorkbench	LO3, LO4
hSim3 (simulation): Heat and temperature: Thermal expansion (Includes taking snapshots and its explanation)	Thermal expansion at molecular level	MolecularWorkbench	LO5, LO6
Dynamic representations (Macroscopic)			
hVid1 (Video): Misconceptions about heat and temperature (YouTube: Veritasium,)	Dr. Derek Muller's experiment and demonstration on heat conduction using metal box, book, ice and human body; difference between heat and temperature	Muller (YouTube video)	LO1, LO2, LO3
hVid2 (Video): Conceptual Physics: Ball and ring expansion demo	Paul Hewitt demos on expansion of metal ring; thermal expansion	Hewitt (YouTube video)	LO5, LO6

	Static Representations		
(Macroscopic and sub-microscopic)			
Images and diagrams	Understanding the concept from both actual and molecular level perspectives	IAMMIC-project (2013) and open source materials from the internet	LO2, LO3, LO5, LO6
	Symbolic representations		
Textual information and instructions Cognitive Conflict Questions (CgCQs) Concept Check Questions (CnCQs) Question Prompts (QPs) Multiple choice questions Synchronous feedback		Some CgCQs and CnCQs have been adopted from IAMMIC-project	LO1, LO2, LO3, LO4, LO5, LO6

As shown in the above *tables 4-7* and *4-8,* a number of simulation models, playing the central role in student activities were employed in this study. The computer simulations were drawn from two prominent research institutes, namely Molecular Workbench by Concord Consortium (MolecularWorkbench) and the PhET Interactive Simulations project at the University of Colorado (PhET). The Molecular Workbench simulations provide highly interactive simulations designed to help learners to learn complex, abstract scientific concepts (Tinker et al., 2008). These simulations have the ability to create lively graphic demonstrations that help students to understand the essential features of the dynamic system. They provide students an environment where they can examine the system frame-by-frame, change the parameters and can start or stop easily where necessary (Q. Xie et al., 2006). On the other hand, PhET simulations are designed to help students visualize the unseen world in different domains of physics, chemistry and biology through the microscopic and macroscopic graphics and built-in controls. PhET simulations offer students the opportunity to explore and understand the concept by providing them an authorizing control system that includes features such as click-and-drag, manipulation, buttons, and so forth. PhET also provides students a unique feature, that is, 'virtual apparatus' such as rulers, stopwatches, voltmeters, thermometers, and so forth to measure and record the data. PhET simulations are particularly useful for understanding cause-and-effect due to its user control, dynamic feedback, and use of multiple representations (PhET). The following section 4.5.1 discusses the two examples of interactive simulations taken from the Molecular Workbench and PhET.

4.5.1 **Examples of simulation models**

Example 1 (Molecular Workbench simulation): The simulation '*hSim1: Mixing hot and cold chamber'* in figure 4-10, used in the Heat module. This simulation was developed to support teaching the science of atoms and molecules across disciplines through the use of the Molecular Workbench under the sub-category of "Motion and Energy". In this study, this simulation was used to facilitate student understanding of the heat transfer process. The simulation represents a closed system of two chambers separated by a door. One chamber contains hot (highlighted as red) gas molecules, while the other one contains cold (highlighted as blue) gas molecules. When students click on the 'Run' button, the door between the two chambers is removed and the simulation starts.

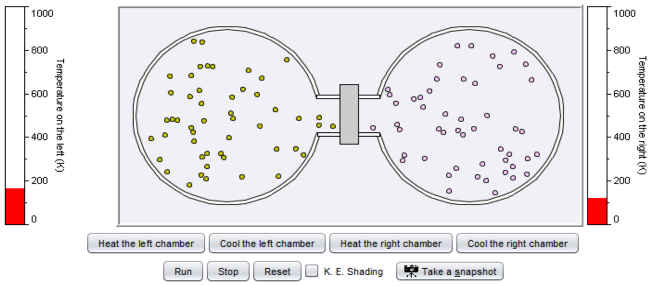


Figure 4-10: Heat transfer between two-closed chambers

Once the student is able to interact with this simulation, they have the opportunity to explore the following concepts to gain insights into the following:

1. How the heat transfer process takes place in the gaseous form;
2. Understand and visualise the role of kinetic energy in relation to the heat and cold;
3. Understand the role of heat in increasing or decreasing the temperature of a system;
4. See the molecular level interaction of how hot and cold gas molecules are mixing; and
5. Understand the thermal equilibrium in a closed system through the molecular level visualisation.

In this simulation, the student can add or remove heat from both the chambers. They need to focus on the molecules' kinetic energy and the temperature of the two chambers as they approach thermal equilibrium. Students need to establish the relationship of heat, kinetic energy and temperature through the mixing of hot and cold particles between the two chambers. This simulation provides students the ability to take snapshots of the simulation events using a tool that can be used to take a picture at any time point in the simulation. Once the snapshot button is clicked, a window with a picture of that moment of the simulation appears and gives students the opportunity to explain what is occurring in the text box. To provide a clear visual experience of how heat is moving, a kinetic energy shading button is embedded within the simulation model. Once this button is clicked, the hot molecules become red. The greater the heat is in the molecule the more reddish it becomes. It provides students a graphic experience of how heat moves from hotter to cooler particles.

Example 2 (PhET simulation): The simulation '*pSim1: States of Matter: Basics*' was taken from the PhET Interactive Simulations project developed at the University of Colorado (PhET). It shows molecular level representations of different substances in different phases (see *figure 4-11*). The simulation presents four atoms and molecules of water, oxygen, neon and argon. Students are familiar with phase changes of water at the macroscopic scale but are unfamiliar with terms at the molecular-level perspective. In this simulation, a student can heat, cool and compress atoms and molecules and watch as they change between the solid, liquid and gas phases. Through this experiment, students are able to learn and describe the characteristics of three states of matter: solid, liquid and gas. This simulation comprises multiple concepts with multiple variables that a student can manipulate. This exploratory process can lead to the apprehension of some key concepts and processes, notably the following:

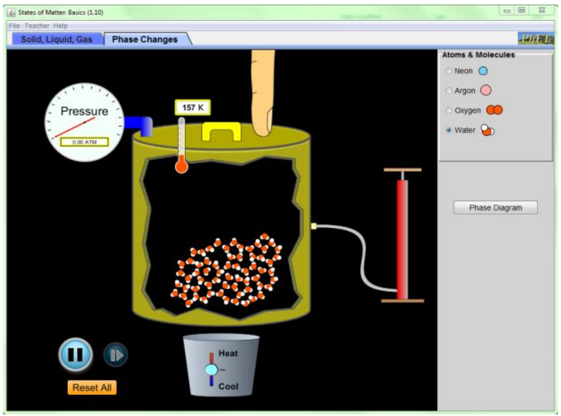


Figure 4-11: PhET simulation, 'States of matter: Basics'

1. Understanding the characteristics of three states of matter: solid, liquid and gas;
2. Predicting how varying the temperature or pressure changes the behaviour of particles in different states;
3. Recognizing that different substances have different properties, including melting, freezing and boiling temperatures;
4. Understanding temperature effects (Heating or cooling) on the changes of the atomic structure of different substances in solid, liquid or gas phases in a close system;
5. Understanding the advanced concept: Effect of pressure (increasing or decreasing the number of molecules, or the volume of the closed container) on the changes of the atomic structure in solid, liquid or gas phases; and
6. Understanding the advanced concept: Confirming Boyle's law (Why the pressure doubles when the volume is halved) and so forth.

There are several features and parameters embedded in the PhET simulation that a student is able to use to explore the simulations. These are: stop/play/reset functions, a heating and cooling function, the choice of four different atoms or molecules (Neon, Argon, Oxygen, Water), solid, liquid and gaseous state buttons, container lid (to control volume of the container), barometer (to explore pressure) and the water phase diagram.

The above examples represent two out of the total of eleven simulations used in this study. In addition, this study utilized three videos, one of which is a video animation employed in two different modules. The following section discusses the videos used in the learning modules.

4.5.2 **Examples of videos**

After extensive use of the simulation and working with the atoms and molecules, students had the opportunity to experience some key concepts by experiencing the videos and animations in the learning modules. These videos and animations are focused on key concepts that the students have already experienced in the simulation activities. The purpose is to further refine student understanding of key concepts. This offers them a different mode of learning and helps them deepen their knowledge and understanding of these concepts. The following are the two examples of video and video animations used in the *Phase Change* and *Heat* Module.

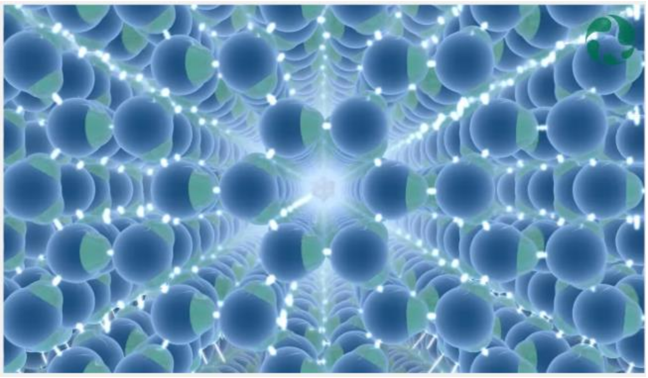


Figure 4-12: Structures and arrangement of water molecules in solid

Example 1: The video animation '*pVid1: Structure of solid, liquid and gaseous state'* was taken from the YouTube channel Canadian Museum of Nature (Canadian-Museum-of-Nature) and is used in the Phase change module. This is an animated video (*figure 4-12*). In approximately 1.45 minutes, it illustrates how the water molecules interact with each other at the molecular level. It displays the structures of water molecules in solid, liquid and gaseous phases as they are moving and vibrating. Students observe how the water molecules organize and construct themselves in the three states of liquid, solid and gas. A brief description is provided for what is happening in each of the stages so that students can read and visualise the phenomenon at the same time. The video is brief and specific to illustrate the water molecules structures and behaviour in three different stages.

In this video animation, students are expected to learn the structures and arrangement of water molecules in three different states. Students experience the hexagonal structure of the ice, which is helpful for students' deeper understanding about why ice floats in water.

Figure 4-13: Heat conduction in different materials

Example 2: This video was taken from the YouTube Chanel 'Veritasium' created by Dr. Derek Muller (Muller) and used in the Heat module. It reveals why different materials feel warmer or colder to the touch even though they are at the same temperature. Dr. Derek uses a book, a metal hard drive and an ice cube in their experiment to demonstrate the concept for those uninitiated in this area of scientific knowledge. This video is about 4 minutes long (*figure 4-13*). It explains people's misconception about heat and temperature, and what they experience when they touch an object in cold weather. Through the video, students learn the concept of the heat transfer process in different materials. Students understand molecules' conductivity between two objects and how heat moves between the human body and metal and plastic. Students learn that the metal could make the ice melt faster because of the quicker heat conductivity in that substance. It also explains why metal feels colder than the plastic at the same temperature.

The above four examples (two simulations and two videos) discuss the external representations of macroscopic and sub-microscopic phenomena of abstract science concepts used in the learning modules. The intention of providing macro and sub-micro level representations was to facilitate students' deep engagement and learning in the modules. However, these representations alone could not provide an effective learning environment unless they were guided by a suitable scaffolding strategy. Earlier studies revealed that the benefits received from multiple representations depend upon students' ability to understand and make connections between them (Ainsworth, 2006; Bodemer et al., 2006; Rau et al., 2015). An instructional support to help them to make those connections is required (Rau et al., 2015). Research has found that when multiple external representations were provided with instructional supports, learning was improved (Bodemer et al., 2006). To this end, this study has embedded different types of instructional guidance to facilitate student engagement and learning.

4.6 Instructional guidance

Giving instructional support is essential to the success of student learning (Luo, 2015). However, there is an ongoing debate about the nature and level of guidance that needs to be provided to students in a constructivist environment (R. Clark et al., 2011). Some researchers have argued that students benefit most when the guidance provided is of a minimal or moderate degree, as students construct most of the knowledge by themselves (Duffy et al., 1992; Savery et al., 1995). These levels of guidance are exemplified in the science domains through instructional approaches such as inquiry learning, discovery learning, experiential learning and constructivist learning (Kirschner et al., 2006). Conversely, many researchers increasingly believe that fully guided instructional support, which has also been known as direct instruction (Klahr et al., 2004), explicit instruction (Gersten et al., 2009), and guided experiential learning (R. Clark, 2009), is indispensable for learning across a wide range of disciplines, learning contexts, and environments (R. Clark et al., 2012; Kirschner et al., 2006; Luo, 2015). Fully guided instruction means it provides all the necessary information and relevant learning strategy support required to bring to fruition student learning of concepts and procedures (Kirschner et al., 2006).

It is to be noted that the above discussions are all about the instructional guidance prevalent in the traditional teaching environment regardless of the technology use. This study differs from that of classroom settings in that its focus is on the online environment. As discussed earlier, this study investigates student learning in the absence of teacher support so that students are in control of their own learning processes. As such, students are located in a constructivist learning environment; in this case they were involved in inquiry learning. Students were required to construct their knowledge with varying degrees of guidance, from open exploration, strong (step-by-step) guidance through to minimal guidance being provided. Even when strong guidance was provided, it was plausible nevertheless that students might follow different directions that could lead them on a path of inquiry learning to self-explore various abstract science concepts.

The benefits of guidance in constructivist learning have been clearly demonstrated in earlier research (Lazonder, 2014; van Joolingen et al., 2005). Especially strong instructional guidance is considered to be a key component for effective learning in constructivist learning contexts (Blikstein et al., 2016). However, several studies confirm that open-ended or minimally guided learning potentially increases the success rate at the later stage of the activity. For example, Kapur (2008) suggests that when no guidance is provided to students, it can lead to a productive end in the longer term, though initially, it appears to lead to failure. The built-in affordances of the powerful technological tools potentially help students in this process of undertaking a productive exploration (Blikstein et al., 2016). Exploration is characterized by experimenting with the affordances of the environment in a playful and flexible way (March, 1991). The nature of this exploration is akin to a discovery (or inquiry) learning approach and supports the constructivist view of learning (Blikstein et al., 2016).

This study placed the educational simulations in the central role of supporting student exploration. The simulation is considered one of the most suitable technological tools to facilitate inquiry-based learning and promotes the constructivist pedagogy in science instruction (Landriscina, 2013). Therefore, under the *Observe* phase of the main POEE scaffolding strategy, simulation activities were scaffolded with varying instructional supports, that is, through providing strong, moderate and minimal (or, open exploration) guidance. The following *table 4-9* illustrates the nature of instructional support and the relevant representational components used in this study.

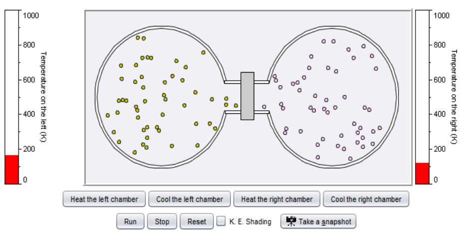
Table 4-9: The nature of instructional support and the relevant representational components

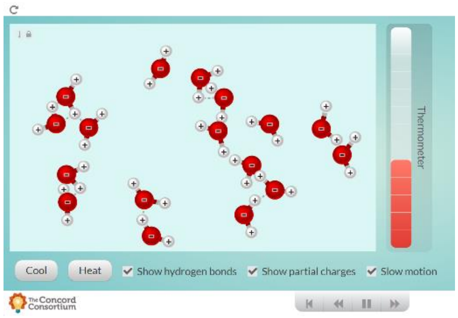
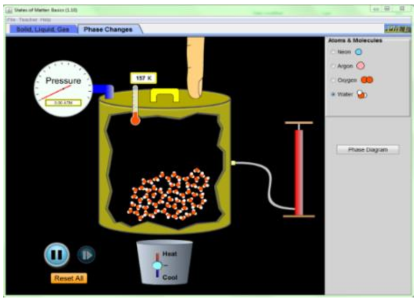
Instructional guidance	**Representational components**	**Functions**	**Potential outcomes**
Strongly guided	Both graphical and symbolic representations are used, in	<u>Guided learning</u> Students receive detailed science instruction of what to do to understand the concepts in the	Students construct knowledge and learn concepts by following the guided instructions.

	particular simulations, videos, textual Instructions, questions, highlighted words	simulation environment. Students have the freedom to inquire into different concepts independently.	However, even with explicit instruction, a student might choose to explore the simulations in another dimension to inquire into the unknown.
Moderately guided	Both graphic and symbolic Representations are used, that is, simulations, videos, check concept buttons, hints, questions	<u>Exploratory learning with moderate guidance</u> With moderate instruction, students are placed in inquiry learning contexts and asked to explore and understand the concepts.	Students enlist initial support from the instructions and explore the simulations. They come to understand the concepts through undertaking their independent explorations drawing upon the moderate guidance they receive.
Open-ended (or, minimally guided)	Graphical representation: simulation models and videos	<u>Pure Exploratory learning</u> This creates exploratory learning environments, based on the foundation of constructivist and inquiry-based premises. Students might obtain support and guidance from the built-in affordances in the environment	Students construct their own understanding and learn the concepts through self-exploration.

The above *table 4-9* discusses the three types of guidance provided in the learning modules, that is, strong (fully guided), moderate and minimal guidance/open-ended. The following *table 4-10* shows the examples of each type of instructional guidance used in the learning modules.

Table 4-10: Examples of instructional guidance used in the learning modules

Instructional guidance	**Examples**
Strongly guided	<u>Extracted from the *Heat* module</u> In a closed room, it is assumed that the temperature is the same everywhere. What happens if you open a door between a hot room and a cold room? Let's examine this by studying the following model: <u>Activity 1</u> **1.** Click 'Run' and then observe for a minute or two. What change occurs when the particles: a) mix together, b) reach equilibrium, c) temperature become the same in both chambers **2.** Click "Run" and then click the "Heat the left chamber" and "Cool the left chamber" tabs at the bottom of the simulation screen to study what occurs when there is no barrier between a hot room and a cold room. Do the same for the right chamber.  Figure 4-14: Heat transfer between two-closed chambers **3.** Tick the "K.E. Shading" (kinetic energy shading) tab. Particles with higher kinetic energy are shaded red, while those with lower energy are white. Note how the shading changes as the chamber contents are heated and cooled.

	Note: While running the simulation, take snapshots of the important moments and changes that occur during the simulation. Once you take a snapshot, a pop-up window will allow you to enter text to accompany the snapshot. Please briefly explain why you think the captured moment is important.	
Moderately guided	Extracted from *Phase change* module Now use the simulation to explore the behaviour of water molecules. Can you see the interactions between the hydrogen atoms with the oxygens close by? These are particularly strong dipole-dipole interactions called hydrogen bonds. Try heating and cooling the water to see the changes. To see the changes in bonding use the 'slow motion' button and try the 'step back' and 'step forward' button. We come to know that water molecules behave differently due to hydrogen bond.	 Figure 4-15: Hydrogen bond in water molecules
Open-ended (or, minimally guided)	Extracted from *Phase change* module The following PhET simulation entitled 'States of matter: Basics' allows you to explore the molecular properties of water and investigate the two questions you just answered.	 Figure 4-16: States of matter (PhET simulation)

Alongside the instructional guidance, this study adopted different types of questions to guide students' inquiry in the learning process. The following section discusses the types of questions and their impact in the learning modules.

4.7 Inquiry questions

Questioning is an important element of scientific inquiry that guides students in meaningful knowledge construction and learning (Chin, 2007; Kawalkar et al., 2013). Questions can create an environment to promote students' scientific inquiry in which students are self-directed and engaged in understanding the scientific concepts (Crawford, 2000; Eick et al., 2002). Typically, this questioning is governed by teachers in traditional settings. The questions asked by the teacher influence students' thinking as they engage in the process of meaning making and construction of scientific knowledge (Chin, 2007).

In science inquiry learning, these questions can be posed and answered in multiple ways (Oliveira, 2010). For example, a student can adopt a lower level thinking approach to answering the questions. To facilitate deep thinking and meaningful investigation, questions need to be asked that require students to do more than reproducing the information and descriptions of the procedures of past events (Oliveira, 2010). Therefore, questions need to be posed that encourage students to think about the underlying scientific reasoning pertaining to the concepts and procedures (Koufetta-Menicou et al., 2000; Oliveira, 2010).

This study draws upon the same perspectives for posing questions as a teacher would in traditional settings, for example, to challenge students' inconsistent views, help them to articulate their initial concepts, to elicit their ideas to resolve confusions, help them to explain, elaborate and reflect on their understanding by providing a setting for inquiry learning (Chin, 2007; van Zee et al., 2001). For this purpose, this study has employed five types of questions, namely cognitive conflict questions (CgCQs), question prompts (QPs), concept check questions (CnCQs), confidence check questions (CfCQs) and multiple choice questions (MCQs). Collectively they are referred to as *inquiry questions* drawing attention to the common nature of the questions that elicit students' thinking about a topic and to facilitate inquiry relating to the scientific concepts addressed by these questions. The following *table 4-11* illustrates these questions:

Table 4-11: Types of Inquiry questions

Inquiry Questions	**Functions**	**Scaffolding phase**
Cognitive conflict questions (CgCQs)	Elicit what students know, encourage them to elaborate on their thinking, and help them to resolve the problems	Predict (P)
Question prompts (QPs)	Encourage students to explore the concepts, look for evidence in the learning modules, guide them to inquire into meaningful and productive exploration	Observe (O)
Concept check questions (CnCQs)	Facilitate students in explaining what they have understood, help them to evaluate and reconstruct their knowledge	Explain (E)
Confidence check questions (CfCQs)	Reflect on what they have understood and explain, help them to refine and modify their understanding and scientific reasoning	Explain (E)
Multiple choice questions (MCQs)	Serve the same purpose as concept check questions (CnCQs), e.g., facilitate students to explain what they have understood, help them to evaluate and reconstruct their knowledge by encouraging them to revisit the simulation models	Explain (E)

To summarise, these questions guide students' inquiry learning. The following sections discuss these four types of inquiry questions with examples.

4.7.1 **Cognitive Conflict Questions (CgCQs)**

CgCQs are used to raise cognitive disequilibrium so that students embark on an inquiry path to restore cognitive equilibrium (Craig et al., 2004; Piaget, 1985). This process is encouraged to activate students' prior knowledge and for providing conceptual direction towards understanding, extending their ideas and scaffolding their thinking (Chin, 2006; Osman et al., 1994). To this end, this study used a number of CgCQs across the two learning modules. The following is the list of CgCQs employed in this study.

Table 4-12: Examples of Cognitive Conflict Questions (CgCQs)

Cognitive Conflict Questions (CgCQs)	
Phase Change	**Heat Module**
CgCQ1. Gases, liquids and solids are all made up of microscopic particles called atoms, but the behaviour of these particles differs in the three phases (solid, liquid and gas). Explain what factors determine the nature of the behaviour of these particles in the different phases.	CgCQ4: On a cold day, when you grab a metal box with your bare hand it feels very cold. When you hold a second box, which is made of plastic it does not feel cold. Explain why the metal box feels colder than the plastic box.
CgCQ2. Now that you have figured out that all molecules are attracted to each other, how can you explain why water and oil don't stay mixed if you shake them up together?	CgCQ5: How does heat move from one material to another? Explain in molecular terms.
CgCQ3. How can water move from pools and rivers into clouds? Explain the processes at the molecular level.	CgCQ6: Rail lines can buckle in very hot weather. Explain how this might occur in molecular terms.

4.7.2 Question Prompts (QPs)

In their study, Ge et al. (2004) discussed three types of question prompts: procedural, elaborative, and reflective. These questions can be used to scaffold student activities by providing them support in problem solving. Procedural prompts support students to identify and analyse the features and functions to complete a specific task. Elaboration prompts help students to articulate thoughts, construct explanations, make justifications, and carry out reasoning related to a problem scenario. Reflective prompts help them to reflect, and self-monitor the learning process. Below in *table 4-13* are examples of question prompts used in the modules.

Table 4-13: Examples of question prompts

Question prompts (QPs)	
Phase Change	**Heat**
QP1. [***Reflective***] Now think about the following: How do the attractions (green lines) differ between the non-polar and the polar molecules? How do the colours, representing the charges of the dipoles, change? What does this mean for the instantaneous dipoles? [Simulation model**:** pSim8]	**QP9**. [***Reflective***] You may have noticed that metal objects often feel colder than plastic or wooden objects that are at the same temperature, so why do they feel different? [Video**:** hVid1]
QP2. [***Procedural***] In the following simulation, which type of molecule clumps together most tightly? **[**Simulation model**:** pSim3]	**QP10**. [***Procedural*** and ***Elaborative***] What happens if you open a door between a hot room and cold room? [Simulation model: hSim1]
QP3. [***Reflective***] Can you relate what you see in the simulation why water is more dense than oil? **[**Simulation model**:** pSim3]	**QP11**. [***Elaborative***] Carefully compare each conductor and analyze all of your readings. Which conductors allows the solids to reach equilibrium fastest? [Simulation model: hSim2]
QP4. [***Reflective***] Now use the simulation to explore the behaviour of water molecules. Can you see the interactions between the hydrogen atoms with the oxygens close by? **[**Simulation model**:** pSim5]	

QP5. [***Procedural*** and ***Elaborative***] The following two JMOL representations illustrate the liquid and solid states of water at the molecular level. Identify the individual water molecules in each of the states of mater. How are the structures of the two forms different? **[**Simulation model**:** 3D JMOL view] **QP6.** [***Reflective***] By now you have a clear picture of water molecules in solid and liquid states. Can you imagine how the properties of water change between the liquid and vapour states? **[**Simulation model**:** pSim6 and pSim1] **QP7**. [***Elaborative*** and ***Reflective***] Use the simulation to confirm Boyle's law. Why the pressure doubles when the volume is halved? Can you think in molecular terms? Find the relation in the simulation **[**Simulation model**:** pSim1] **QP8**. [***Elaborative*** and ***Reflective***] Explore the solid-liquid phase change for water and estimate the melting point of water in the simulation. Why is it so difficult to get a precise figure? **[**Simulation model**:** pSim1]	**QP12**. [***Reflective***] Why is heat transferred more quickly in solids than in gases? [Simulation model**:** hSim2]

4.7.3 Concept Check Questions (CnCQs)

This study uses CnCQs to help students explain their answers in order to facilitate their deep conceptual understanding. As inquiry questions, CnCQs are potentially stimulating, challenging and exploratory; they are questions that help students to articulate and elaborate their ideas, and can be used to scaffold their thinking in achieving conceptual development (Oliveira, 2010). In traditional settings, inquiry questions often prompt students to demonstrate their science understandings meaningfully by promoting extended written responses (Nieswandt et al., 2009); CnCQs used in this study's learning modules serve the same purpose. Students were required to explain their answers in written form. During the writing process, if students found that their comprehension was incomplete, they could revisit the activities and inquire into the concept again for a more complete understanding. The key purpose of using CnCQs in this study was to elicit students' experiences and facilitate in developing more refined meanings from their own individual experiences (van Zee et al., 2001). The following are the examples of CnCQs used in this study:

Table 4-14: Examples of Concept check questions (CnCQs)

Concept Check Questions (CnCQs)	
Phase Change module	Heat module
CnCQ1. Explain why water is often liquid, but oxygen (O_2) is always a gas at room temperature. **CnCQ2**. What is the difference between evaporating and boiling? **CnCQ3**. If you get out of a hot shower, you will often find the bathroom mirror is fogged up. Explain why this happens.	**CnCQ7.** Use the Kinetic molecular theory to explain the temperature change that occurs when a cold and a hot liquid are mixed. **CnCQ8**. In a popular lecture demonstration, a rod that is half wood and half metal is wrapped tightly with a sheet of paper. If held over a flame, the paper on one-half of the rod burns while the paper

CnCQ4. 'Water molecules do not move in the solid (ice)' - Do you agree or disagree? Explain. **CnCQ5.** Explore the simulation of water molecules to explain why ice floats in molecular terms. **CnCQ6.** Explore the simulation at point B. This is the critical point and beyond, it is the supercritical phase. What are the molecular properties of this phase of water? Supercritical water is used in power stations. Suggest a possible reason why supercritical water is a better water phase to use than conventional steam turbines?	on the other half is unaffected. Which half of the rod has the burnt paper? Explain with reasoning. **CnCQ9.** A vacuum flask (Thermos flask) is a double-wall container with a vacuum between the two walls. How does the flask keep its contents hotter or cooler than the outside air? Explain your answer using kinetic molecular theory. **CnCQ10.** The iron plate pictured here has a hole cut in its centre. What will happen to the hole when the plate is heated? Explain in molecular terms with reasoning.

4.7.4 **Multiple Choice Questions (MCQs)**

Throughout, this study placed greater emphasis on students' written responses and used the students' written responses as the key data source to analyse their understanding in the POEE activities; several multiple-choice questions (MCQs) were also employed to facilitate students' understanding. Students received synchronous feedback for each option of MCQ they selected. There are 6 MCQs and 5 MCQs used in Phase change and Heat module respectively. Below are few examples:

Table 4-15: Examples of Multiple Choice Questions (MCQs)

Phase Change Module: *6 MCQs- MCQ1, MCQ2, MCQ3, MCQ4, MCQ5, MCQ6*		
Example questions	**Possible answers**	**Correct answer**
MCQ5. In a boiling hot pool, when water evaporates, liquid water changes into vapour (steam). What is the chemical composition of steam?	A. O_2 and H_2 B. N_2 and O_2 C. H_2O D. Air E. All of the above	C
MCQ6. Why is the water vapour less dense than the liquid water?	A. Because the molecules in water vapour have more energy and no longer stick together B. When heated, water vapour molecules weigh less than liquid water molecules C. Because molecules of water vapour release energy and becomes lighter D. Water vapour is gas, so it is lighter than water	A
Heat Module: *5 MCQs- MCQ7, MCQ8, MCQ9, MCQ10, MCQ 11*		
MCQ10. Why is heat transferred more quickly in solids than in gases? Choose the best possible answer.	A. The atomic structure of solids is more dense than that of gases, so the atoms come into contact with each other more often. B. Heat is a substance that can move more quickly in a solid than in a gas. C. Charged particles in solids cause faster heat transfer than in gases. D. In solids, heat transfer occurs through both convection and conduction processes and is therefore faster.	A

MCQ11. Consider two iron rods held at 70 ºC. Iron rod A is 50 m long, while rod B is 100 m long. If the temperature decreases from 70 ºC to 40 ºC, then:	A. the length of rod A will decrease more than the length of rod B B. the length of rod B will decrease more than the length of rod A C. the length of each rod will decrease by the same amount D. none of the above	B

4.7.5 Confidence Check Questions (CfCQs)

Zee et al. (1997) suggested an important reason for using questions in inquiry settings was to promote students' reflections on the given problem during the inquiry learning process. The purpose of this reflection is to elicit and guide student thinking further by posing questions that encourage students to articulate their own thoughts and ideas. To this end, this study used a question referred to as the '*confidence check question'*, one that is posed after every written response in order to help students to reflect on their answer. Research shows that when the responsibility for thinking is handed back to students by asking a question of them, it helps them to be thoughtful in their responses (van Zee et al., 1997a). van Zee et al. (1997b) found that this reflective process helped students to clarify their meanings by considering multiple ways to understand the concept and to engage in monitoring their own thinking. This study used the CfCQs for the same purpose. The following is the example of such a question used across the activities.

Table 4-16: Examples of Confidence Check Questions (CfCQs)

Confidence Check Questions (CfCQs)
How confident are you about your answer? Select below*: 4- Very high 3- High 2- Low 1- Very Low *Students' confidence level was checked in 4-rating scale

Students were required to choose their confidence level from 'Very high' to 'Low' after finishing their written responses. The option of choosing their level of confidence can assists students to rethink their answers. Sometimes it can lead students to revisit the activity and modify them.

4.8 Feedback

The provision of synchronous feedback to students, in the absence of teachers, can reduce confusions and clarify students' understandings. Research shows that effective and quality feedback to be an integral part of the learning process (Ramsden, 2003). Student activity without feedback in the learning process is unproductive (Laurillard, 1993). Effective feedback can provide the evaluative or corrective information about student activity, or process to facilitate and foster learning (Hattie et al., 2007; Wing, 1990). Feedback works in multiple ways to help students; it is crucial for the evaluation of their answers, to facilitate their competencies and understanding, and to promote motivation and confidence (Hyland, 2000).

Feedback in the technology-enhanced environment during the learning process enhances students learning (Avner, 1980; Jerry et al., 2013). In online settings, new technologies play an important role to expand the ways in which feedback can be provided (De Hoyos et al., 2005; Kearney, 2003). This study, using the sophisticated technology integrated within the web environment, provided students feedback with textual explanations, and in some cases with supporting images and videos. This synchronous approach to feedback facilitated students in their reflective understanding enabling them to progress in evaluating their understandings. Therefore, feedback can be considered a powerful tool in online learning that supports the development of self-regulation (Keiding et al., 2014). The following are few examples of synchronous feedback that this study used in the learning modules:

Table 4-17: Examples of synchronous feedback

Questions	Examples of feedback
CnCQ1. Explain why water is often liquid, but oxygen (O_2) is always a gas at room temperature.	A possible explanation is: water molecules are strongly held together by hydrogen bond. Oxygen molecules are nonpolar and so they form a gas because the intermolecular forces are too weak to hold them together in spite of oxygen molecules having more mass than water molecules.
CnCQ9. A vacuum flask (Thermos flask) is a double-wall container with a vacuum between the two walls. How does the flask keep its contents hotter or cooler than the outside air? Explain your answer using kinetic molecular theory.	When hot content is in the flask the heat is prevented from escaping as it cannot be conducted through the vacuum (as there are no molecules). When a cold content is in the flask the heat outside cannot conduct through the same vacuum to heat the content inside. Since there are no gas molecules in the vacuum there can be no convection of heat across the void either.
MCQ6: Why is the water vapour less dense than the liquid water? A. Because the molecules in water vapour have more energy and no longer stick together B. When heated, water vapour molecules weigh less than liquid water molecules C. Because molecules of water vapour release energy and becomes lighter D. Water vapour is gas, so it is lighter than water	<u>Feedback for correct selection</u> Yes. Wonderful job! Because the molecules of water separate, and they take up more space, so the density decreases. <u>Feedback for incorrect selection</u> Incorrect answer! What is the effect of heating liquid water molecules? Recall that the density of a substance decreases when the volume increases. Watch it in the simulation again.

4.9 Online deployment and delivery

This study deployed and delivered the two learning modules as web content to students. For this purpose, two domain names were purchased from two different Internet hosting services. One domain is www.mystudyhome.com and the other one is www.estudyhome.com. Initially, the first domain was bought, and the contents were deployed to that website. However, due to some technical issues in the server that hindered the smooth access to the first site, the second site was bought and developed. The Adobe Dreamweaver software was used in the initial stage to develop and deploy the contents to the websites. Later on, the free and popular open-source content management system (CMS) WordPress was used to develop and deploy the contents. After finishing the data collection, the first website was closed down. However, the researcher still owns the second website, but the contents have been removed.

4.10 **Conclusion**

In this chapter, the design of the two learning modules have been discussed; these were built on a platform of constructivist theory to promote students' inquiry learning. The POEE activities embedded with sophisticated MERs, instructional guidance, questions prompts were designed as an instrument to elicit students' initial ideas which then led students to probe their understanding and provided them with an opportunity for learning. Such an application of the POEE strategy is a novel approach in the sense that the learning modules represent a new development in the use of the POEE strategy in the self-directed online inquiry environment within the context of science education. The adaptation of the POEE in itself is a significant innovation as it introduced a formative evaluation phase 'Evaluate (E)' enhancing the original POE scaffolding strategy to help students reflect and evaluate their learning in the self-directed environment. Discussions of the design and development process of the scaffolded learning modules presented in this chapter have the potential to facilitate a greater understanding and further insights into the implications and uses of sophisticated technology for inquiry learning in online settings.

Chapter 5
The Role of Scaffolding in Online Learning

5.1 Introduction

This chapter outlines and discusses the findings of four aspects of the project: the POEE as the primary scaffolding strategy, and, in addition the multiple external representations, instructional guidance, and the inquiry questions enlisted as the secondary scaffolding tools. These complementary strategies provide multiple ways that students can address the different aspects of the underlying concepts. This inquiry process undertaken by students is facilitated by instructional guidance provided in company with the formulated inquiry questions. The intention of this study was to engage students in activities which prompted them to think more deeply about what they were learning. The findings revealed the importance of multimodal scaffolding in the absence of interpersonal guidance to students. It was found that four dimensions of scaffolding predict, observe, explain and evaluate were required to support students' inquiry through each module. Specifically, the *evaluate (E)* phase supported students' processes of self-reflection and clarification of their understandings, an undertaking that would not have been possible without this dimension in the online environment.

5.2 Predict phase (P)

In the Predict phase, Cognitive Conflict Questions (CgCQs) were used to scaffold students' conceptions helping them to construct ideas and regulate their thinking around each problem. These were given to students after they had seen an initial component of the module such as introductory texts, relevant images with the purpose of trying to get them to think about the concepts from a particle level. The following table 5.1 shows the key themes that emerged in the Predict phase and is followed by detailed discussions in section 5.2.1 and 5.2.2.

Table 5-1: Themes that emerged in the predict phase

	Key Themes	**Data sources**
Predict phase (P)	CgCQs elicit initial ideas and help students construct their knowledge about the concepts (conceptual scaffolding) CgCQs regulate students' thinking to help them understand the concepts (metacognitive scaffolding)	Interview and written responses

The following two sub-sections discuss the results of the emerging themes and sub-themes in relation to the conceptual and metacognitive scaffolding functions.

5.2.1 Cognitive conflict questions (CgCQs)

Cognitive Conflict Questions (CgCQs) were found to work positively in relation to both conceptual scaffolding and metacognitive scaffolding. Examples of CgCQs used in this study are listed in '*Chapter 4: Learning Modules Design; section 4.6.1'*. CgCQs were embedded in the online modules prior to each activity being undertaken by the students in order to elicit students' initial ideas and facilitate their knowledge construction. Table 5-2 below summarizes the themes and subthemes that emerged from the *Predict phase* related to concepts that students identified.

Table 5-2: Themes and subthemes emerged from the CgCQs (conceptual scaffolding)

Theme	Subtheme	CgCQs	Concepts identified by students in their written responses	Examples of student written responses
				Phase change module
CgCQs elicit student initial ideas and facilitate knowledge construction towards the targeted concepts	Students think and explain concepts at molecular level	**CgCQ1**	Intermolecular structures, intermolecular attractions, molecules movement and speed	*When the atoms are compact together in a fixed shape it is a solid, when the atoms fill the bottom of the container, are not in a fixed state and can move it is a liquid. When the atoms are spread with plenty of areas to move in reaching all parts of the container it is a gas. Temperature changes cause the states to change.* [PHSEM 104; ref: CgCQ1]
		CgCQ2	Polar and non-polar concepts, Intermolecular attraction/ repulsion	*Hydrophobic molecules in oil repel them from water. Water is polar, oil is non-polar thus the two repel.* [PHSEM 105; ref: CgCQ2]
		CgCQ3	Breaking hydrogen bonds, molecules excitement and vibration, molecules kinetic energy, evaporation of water molecules	
				Heat module
		CgCQ4	Thermal conductivity at molecular level	*When a substance is hot, it has lots of kinetic energy. When something has lots of kinetic energy, it's kind of vibrating or moving around more on a molecular level. Maybe when there is enough kinetic energy, the atoms move further apart, and therefore expand a bit.* [HTSEM 106; ref: CgCQ6]
		CgCQ5	Collisions between the molecules, molecules vibrations, molecules kinetic energy, Flow of electrons	
		CgCQ6	Molecules vibration, faster movement of molecules, molecules kinetic energy	

			Phase change module
Students make use of their prior understanding and knowledge of the topics	**CgCQ1**	Density, volume, temperature and pressure	*H_20, I am guessing, is more denser and the configuration of intermolecular forces between them is tighter and thus retracting the force of the oil against the bonds.* [PHSEM 106; ref: CgCQ2] *Lipids are hydrophobic and are not soluble in water. The atoms repel each other. Oil does not have permanent dipoles whereas water does.* [PHSEM 103; ref: CgCQ2]
	CgCQ2	Hydrophobic nature of lipids, density of water and oil	
	CgCQ3	Evaporation	
			Heat module
	CgCQ4	Thermal conductivity, effect of atmospheric temperature, Ability to retain/hold temperatures by metal and plastic	*The hot air particles transfer easily via conduction to the railway line. Subsequently, the particles in the railway line that are arranged as solids get "pushed" apart and there is more intermolecular space. This makes the metal more like a liquid (it undergoes a phase change). The phase change that occurs means that the metal is more malleable (maybe just bendable).* [HTSEM 102; ref: CgCQ6]
	CgCQ5	Thermal equilibrium, Temperature difference, Thermal conductivity	
	CgCQ6	Absorption of heat by the materials, phase changes	

The first emergent subtheme confirmed that the intention of the scaffolding had been successful as it elicited students' prior knowledge and helped them to think at the molecular level. Only the CgCQ4 from the *Heat* module did not work well in this regard. CgCQ4 posed the question: '*On a cold day, you grab a metal box with your bare hand. It feels very cold. You grab the second box, which is made of plastic and does not feel cold. Explain why the metal box feels colder than the plastic box'*. In response to this question, students addressed the problem situation from their general perceptions of the problem and based on their initial understandings. Three examples are given below to support this claim.

> The metal box feels colder because it is a better conductor of heat than a plastic box, due to the cold surroundings the metal is not hot. [HTSEM103] (Written response)

> Metal is a conductor of heat, and therefore when there is a lack of heat the metal will feel similar to the temperature. [HTSEM105] (Written response)

> Plastic is better at holding heat than metal. [HTSEM108] (Written response)

In the first two examples, students correctly mentioned that metal is a good conductor of heat, as they knew it. So, the elicitation of students' initial ideas was successful; however, they did not proceed to think and explain the concept at the molecular level, which resulted in the explanation remaining ambiguous. So, it seems their construction of knowledge was not well founded. Similarly, the third quote is ambiguous in that it does not mention the conductivity of the metal. Thus, it is evident from this data that the scaffolding strategy of eliciting students' initial ideas was successful, but this initial success was not converted into a realization that enabled them to think and construct their knowledge at a molecular level.

However, other CgCQs worked effectively to facilitate students in constructing their thinking. For example, 'CgCQ2: How can you explain why water and oil don't stay mixed if you shake them up together?' was asked in the *Phase Change* module to draw students' attention to the polarity of the molecules and their intermolecular attractions they had just experienced. The two examples of students' responses in this regard, mentioned in the above *table 5-2,* demonstrated that students transferred the concept of hydrophobic from their prior knowledge and tried to integrate it with the polarity concepts of the molecules to explain why oil and water do not mix. This was a common pattern observed in this study, that is, whenever students encountered cognitive conflict questions they drew upon ideas from their prior knowledge to explain the given phenomena. For example, a student stated in the interview why he used his prior understanding of the hydrophobic concept to understand the given problem:

> I said that because I just learned that in biology that they are hydrophobic. So that's the thing in my head. I was thinking they are hydrophobic, so they are like move away from water. [PHSEM103; ref: CgCQ2]

While the student just experienced the concept of polar and non-polar molecules and their relative intermolecular strengths in the previous activity, an important note is that he did not directly use the newly learned concept to explain the problem but rather connected it to his previous understanding of the hydrophobic concept to explain it. Therefore, the student's prior understanding and newly formed knowledge together contributed to guide his thinking and knowledge construction. Earlier research has suggested that this prior understanding can lead to a positive conceptual change in their learning (Chan et al., 1997). Therefore, CgCQs were found to be useful for conceptual scaffolding in helping students to elicit their prior knowledge and understanding of concepts in the self-directed online settings. These results support the previous research findings undertaken in traditional classroom settings (Hannafin et al., 1999).

Another key theme that became apparent was that CgCQs also triggered metacognitive processes in that they regulated student thinking. Using data collected from individual student interactions and interviews, the following *table 5-3* outlines the theme and subthemes related to metacognitive scaffolding:

Table 5-3: Themes and subthemes emerged from the CgCQs (metacognitive scaffolding)

Theme	Subthemes	Frequency [N=30]
CgCQs regulate students' thinking in understanding the given concepts	Create dissatisfaction (sometimes confusion) in understanding the concepts	14
	Awareness about lack of knowledge and the inability to explain correctly	10
	Dissatisfaction or awareness causes to prompt investigation	19

The first subtheme revealed is that CgCQ created cognitive dissonance in students' minds about what they knew. In many cases, it was ascertained that students were confused and uncertain about their answers while answering CgCQs which resulted in their experiencing dissatisfaction with their responses. When their knowledge about the given problems was inadequate for providing a satisfactory explanation, they were left in a state of disequilibrium. The following examples from interview reflect students' confusions and uncertainty about their answers:

> I was not too sure what caused the... like I know the metal can change shapes when it gets really hot. I had no idea what causes, I just knew that molecules can move around the... but I am not sure actually. [HTSEM105] (Ref: CgCQ6)

> I know that metal is a quicker conductor, but yeah, I would actually be struggling with this because I could not think about it. … I know that I experienced it before and I will be kind of getting frustrated, but I still was not able to replay the information. [HTSEM207] (Ref: CgCQ4)

It is evident from the above comments that CgCQs precipitated student confusion; however, this initial disorientation proved to be positive as this state proved to be catalytic in prompting them into becoming more mindful of their inability to reconcile the concepts with their existing knowledge schema. This is the second subtheme that emerged from the data. The following quotes from interview demonstrate how CgCQs facilitated this awareness:

> I was trying to think ahead about what information was going to be like, to answer the questions right. I knew it (that the information I have) was not going to be exactly right. [PHSEM104]

> I had a vague idea of what the answer might be but before I even knew what answer I was going to put down, I knew I was not confident in that. [PHSEM105] (Ref: CgCQ1)

Therefore, student reflection on their own thinking indicated that inclusion of the CgCQs had prompted an awareness of their own thinking. This was an important consequence of the cognitive conflict experienced (Bao et al., 2013). This awareness prompted students to investigate and explore simulation models to clarify and repair their lack of conceptual understanding.

The third subtheme supports the notion that the previous two subthemes had a combined effect in prompting students to investigate the concepts. This was confirmed by some students in the interview.

I just did not quite know how to answer it. So, I thought just put down what I knew, and then just do the simulation model, like see, if I could learn from there. [PHSEM203] (Ref: CgCQ1)

I knew it (that the information I have) was not going to be exactly right. So, it pushed me to engage (in the activity) to find the information for it. [PHSEM104] (Ref: CgCQ2)

As discussed above, it is evident that students tried to explain the problems with their existing understanding; they "kind of" understood the problem but were unsure whether their understanding was correct or not. This uncertainty escalated in their minds and prompted them to engage with the activity. Such student behaviour was also evident in earlier studies, that is, that dissatisfaction with their current understanding, along with uncertainty pertaining to their degree of understanding motivated students to investigate and explore the simulation models to clarify their concepts (Posner et al., 1982).

To summarize, the CgCQs allowed students to notice the discrepancy between their existing knowledge and the information provided in the problem, leading to a state of disequilibrium (Limón, 2001; Piaget, 1985; Ronda, 2012). At this stage, the scaffolding function worked on two dimensions. First, it encouraged students to think about the given concept and second, the resulting confusion precipitated students to engage in a metacognitive process, which stimulated them to further investigate the concepts to adjust their understandings (Bao et al., 2013; G. Lee et al., 2001).

5.3 Observe phase (O)

Observe phase is the central scaffolding element of the POEE strategy. The key themes that emerged from the *Observe* phase are shown in the following *table 5-4.*

Table 5-4: key themes that emerged in the Observe phase

Observe Phase (O)			
Scaffolding functions	**Examples**	**Key themes emerged**	**Data Sources**
Conceptual	<u>Multiple External representations (MERs):</u> Simulation activities, videos, animations, picture of molecules	Multiple External representations helped students to perceive the concepts of molecular world	Interview, observational notes,
	Question Prompts (QPs)	Question Prompts elicit and guide inquiry	Observational notes, interview, written responses
	Hints and highlighted words	Hints and highlighted words facilitate students' learning	Interview
Procedural	Instructional guidance	Strong instructional guidance facilitated students learning	Interview, observational notes

Each of these themes is unpacked below.

5.3.1 **Multiple External Representations (MERs)**

This study revealed that MERs facilitated students in developing visualization skills, providing a mental model and promoting understanding of the concepts at the molecular level. *Table 5-5* below illustrates the findings related to the themes and subthemes in this regard.

Table 5-5: Theme and subthemes that emerged in relation to MERs

Theme	Subthemes	Key visual elements identified by students	Data sources
Multiple External representations (MERs) helped students to perceive the concepts of molecular world	MERs increased student's visualization skills about the problem situations	<u>Interactive (Simulations)</u> Visualisation of kinetic energy movement with colour changes, molecules spinning and colliding, polar-nonpolar molecular attraction, scales of molecular movement in three phases, making bonds, H-bond structure, 3D structures of liquid water and ice molecules etc. <u>Dynamic (Animations, videos)</u> Formation and deformation of bonds, molecular structure in three phases of water, ice melting faster on metal than plastic, heat causing the iron hole to increase in size and not to decrease, etc. <u>Static (Images and photos)</u> 2D views and structures of the molecules, photos of real life situations etc.	Interview, observational notes

The first subtheme that emerged from the data was the development of students' visualization skills. After challenged through CgCQs in the predict phase, which created cognitive disequilibrium, students encountered and engaged with the simulation models. Students tried to balance this disequilibrium by exploring the simulation models through the path of the inquiry process. In this process, they interacted at the molecular level to understand the given concepts. The sub-micro level representations of the concepts facilitated students to visualize the molecules' behaviour and thus helped them to understand the concepts. Some examples of students' reflections are shown below:

Table 5-6: Students' visualization skills demonstrated in the simulation activity

Examples of students' quote (from interview)	Visual elements identified
I go to water molecules… I see the clash and the distinctions between two edges of the molecules on the way that was spinning and specifically colliding (to each other). I got a sense of the behaviour of molecular interactions, which I suspected, but I never actually seen before in my studies. [PHSEM207] (Ref: pSim1)	Intermolecular interaction: molecules collision, spinning
I did not know before that the electrons are moving so much and that is why they constantly making those different bonds... I also did not know specifically about the polarity… how the bonds clash between the negative and positive forces and how they just stay, like so stable. I could visualise it bit better now even though kind of I knew about non-polar and polar, but not like this. It helps me understand the concept better. [PHSEM103] (Ref: pSim5)	Making and breaking bonds: polar, no-polar bonds, stability of the bonds

I saw these atoms bouncing around. I can see the molecules in a hot area moving a lot faster than transfer through to the cold air, and I can see how that would mix. I can see how that would work with the liquid as well. I could see how a hot substance will influence a cold substance to get equilibrium in temperature. [HTSEM101] (Ref: hSim1)	Molecular kinetic energy, heat transfer: molecules movement, vibration, molecules movement between hot and cold area, thermal equilibrium

It was evident from the above comments that the students' witnessing the dynamic nature of molecules played a key role in increasing their focus on the molecular structure and behaviour. They perceived the differences in the structures and movement of the molecules. They observed the subsequent behaviour of these atoms and molecules resulting from their movement and structure. Through this exploration and inquiry, cognitive equilibrium was restored. In parallel to the simulations, the animations and videos played a similar role in increasing students' visualization skills to help them achieve cognitive equilibrium. The following *table 5-7* shows two examples in this regard.

Table 5-7: Students' visualization skills demonstrated in the video activity

Examples of students' quote (from interview) for video activities	**Visual elements identified**
I just learned a more specific understanding of the behaviour of the molecules. The video, where literally you can see kind of the bonds forming and deforming again, which is really useful kind of image I found. I think that was the most valuable part. [PHSEAM207] (Ref: pVid1)	Formation and deformation of bonds in solid, liquid and gas phases
I liked the video, because I know exactly what is happening. I like how with the solid stage was structured. It was very rigid. So, it was good for me to think, OK, so it's all very structured. And then with the liquid stage, they were a little bit more like unstructured. [PHSEM103] (Ref: pVid1)	Rigid and well-structured molecules in solid phase; unstructured molecular arrangement in liquid phase

These examples confirmed that videos were useful too; they increased students' visual capacities by enabling them to see what occurred at the molecular level. The important role of multiple representations (in this case both simulation models and videos) was that they complemented each other in providing information for understanding a given concept. This confluence of information occurred because they supported different representational and computational efficiencies for learning (Ainsworth et al., 2004). Earlier research also confirmed that, in the inquiry process students' visualisation skills improved with dynamic representations (H. Y. Chang et al., 2013; D. B. Clark, 2006; Ryoo et al., 2012) as were provided by simulation models and videos in this study.

The second subtheme that emerged was how the dynamic nature of the MERs contributed to developing students' mental models about the given concepts. One study revealed that exhibiting the motion of atoms and molecules could develop a stronger mental model of molecular processes (Yarden et al., 2010). This study similarly found that students built an idea about the particular nature of matter and related changes in their properties by observing molecular behaviour on a sub-micro scale. For example, it is impossible to visualise that molecules are vibrating in a solid material through the naked eye. However, when students explored simulations and videos pitched at the sub-microscopic level they realised that molecules vibrated in the solid state of matter. This visualisation at the sub-microscopic level helped students to perceive the idea that molecules are indeed vibrating at all times in all states, even though they are not visible to the eye. Some students confirmed this understanding after the exploration:

> Molecules in solids do move, however, they do not move as rapidly nor, do they spread like that of a gas due to their inability to move. This is due to the restriction they have due to the bonds with other water molecules. Their movement never stops. [PHSEM101] (from interview)

> I remember the image in my mind of atoms, when they're in the solid state, there are still have some just mini scale movement between each other I think. They are not really sort of completely still (in the solid). [PHSEM106] (from interview)

The above examples provide clear evidence that the observation of molecules assisted students to understand molecular behaviour in the various states of matter. While students could not see the molecular level phenomena, the representations provided supported the development of a mental model by illustrating how molecules interact with each other (H. Y. Chang et al., 2013). Of note is that it was the dynamic nature of the molecules that helped them to understand the idea that molecules always move, even in the solid phase. There are other data too that support the conclusion that MERs facilitated students to develop a mental model of the structure and behaviour of the molecules and achieve an understanding of how these impacted on the overall scientific process of phase change and heat conduction. The following *table 5-8* shows some examples extracted from student interviews to support this finding:

Table 5-8: Findings that support the development of a student mental model through MERs

Examples (Extracted from student Interview)	Students' perceived understanding
… Between the different phases, it was always H_2O molecules, and those atoms are together, no matter what stage. I would not probably have thought about it before. I learned it from the module. [PHSEM103] *I actually thought that they (atoms of H_2O) were separate. But I saw the image and from the simulations where they stayed as the three atoms. I did not know that before that they stay together. I thought they all separated.* [PHSEM104]	H_2O is one single molecule in all three stages- gas, liquid and solid
I did not know the two things can feel the different temperature but be the same temperature. And I did not realise the ice would melt more on the cold surface. But when they explained, it makes sense. [HTSEM101] *Because the metal takes the thermal energy, or the heat takes from our body away more quickly from the plastic.* [HTSEM103] *I learned that the metal and the plastic have the same temperature. Metal feels cooler, I learned that because when we are touching the object, metal takes away the heat faster from us than the plastic.* [HTSEM105]	Materials feel cold or hot not because of their temperature but because of how quickly they conduct heat

And that when you touched something you do not really feel the temperature, you are feeling how it's conducting kinetic energy from it to you. [HTSEM106]	towards or away from the body
I like all the pictures and it affects my playing around with the things and I understand it better. [PHSEM103] *I like the pictures. I could visualize that because it was like colour objects and it helps to explain it.* [HTSEM106] *The second picture which shows the thermal energy. The larger object shows high thermal energy than the cold object because it's smaller. It's got a total of less molecules so that it has less thermal energy. That was helpful.* [HTSEM105] *I like the images. It's quite useful. It is engaging.* [HTSEM103]	Pictures are useful to visualize and understand the molecular level process
By the end of it, I was thinking more of like the molecules in cells, but before that I was trying to think of them literally like thinking of the molecules and try to imagine them, but after I got into it towards the end, I think I focused more on the molecular level. At the start, I did not really think of it in that way but after, I sort of got into it. [PHSEM101] *The simulations that made you think of the molecules and the molecules spreading and things like that makes me think on the more molecular level.* [PHSEM101] *Yes, I really appreciate kind of those it ties sort of bonds between different molecules. Yes, it gives a very live understanding if you can take that intuition to heart, very cool.* [PHSEM207]	Students' perception helped them to think at a molecular level

From the above data, it was found that the MERs had assisted a large number of the students to understand correctly that H_2O (the first perceived understanding recorded in the above table) was always a single molecule in every phase. To ascertain to what extent students understood this concept, a question was asked relating to a common misconception held by introductory science students. This question was: "What is the chemical composition of water steam?" The reason for asking this question is that often introductory science students hold the misconception from their school education that the chemical composition of water steam is not H_2O (Johnson, 1998). Through engagement with the MERs, many students were thus able to clearly see the H_2O molecules in the water as steam. Therefore, it was evident that being afforded the opportunity to see the representations strengthened their visual abilities to perceive and apprehend the nature of the molecular structure, a result made possible by the adoption of the MERs providing access for students to interact with them.

Alongside the simulations and videos, static representations of atoms and molecules assisted students in the conceptualisation process as the study showed that integration of different representations was more effective than a single mode of representation (Ainsworth, 2006). As observed, static representations helped students to perceive the molecular structure. For example, in the *Phase Change* module, related pictures of atoms and molecules were shown to students to give them an idea of the structural formation of molecules in different forms of water. Through these sub-micro level static representations of water molecules, students were able to depict the accurate molecular structure ahead of the simulation activity. As each activity progressed, students experienced various types of visual and interactive activities. As in previous research findings, the data above revealed that MERs played an important role in developing the mental model for atoms and molecules (Gilbert, 2005; Rapp, 2005). A form of learning progression was observed through the growing perception of molecular structure and their behaviour through students' experiencing the MERs, where their understanding level transitioned from the observable (macro) to the sub-micro level (Dickson et al., 2016; Gilbert et al., 2016; Gilbert et al., 2009; Meijer et al., 2013). This learning progression afforded the students the opportunity to cognitively delve more deeply. Especially in the inquiry self-directed setting mode, it facilitated their prioritizing key concepts that needed to be processed and understood during learning.

5.3.2 **Question Prompts (QPs)**

Question Prompts (QPs) were found to be a useful scaffolding tool to guide students in the inquiry process to explore specific concepts. The following *table 5-9* illustrates some examples of QPs that helped students to acquire the concepts in the learning module.

Table 5-9: Some examples of Question Prompts

Question Prompts (QPs)	**Specific Concepts investigated**	**Number of students investigated**
Phase Change		**N=13**
QP1. Now think about the following: How do the attractions (green lines) differ between the non-polar and the polar molecules? How do the colours, representing the charges of the dipoles, change? What does this mean for the instantaneous dipoles? [**Simulation model:** dipole-dipole and London dispersion]	Dipole-dipole and London dispersion attraction	9
QP2. In the following simulation, which type of molecule clumps together most tightly? **[Simulation model:** Mixing water and oil]	Polar and non-polar bonds	10
QP3. Can you relate what you see in the simulation why water is most dense than oil? **[Simulation model:** Mixing water and oil]	Molecular structure of water and oil	7
QP4. Now use the simulation to explore the behaviour of water molecules. Can you see the interactions between the hydrogen atoms with the oxygens close by? **[Simulation model:** Hydrogen bonding]	Hydrogen bond	4
QP5. The following two JMOL representations illustrate the liquid and solid states of water at the molecular level. Identify the individual water molecules in each of the states of mater. How are the structures of the two forms different? **[Simulation model:** 3D JMOL view]	Water molecules structure in liquid and ice	11
QP6. By now you have a clear picture of water molecules in solid and liquid states. Can you imagine how the properties of water change between the liquid and vapour states? **[Simulation model:** Evaporation and PhET: States of Matter]	Physical properties of water	10
QP7. Use the simulation to confirm Boyle's law. Why the pressure doubles when the volume is halved? Can you think in	Boyle's law, relations between volume,	5

molecular terms? Find the relation in the simulation **[Simulation model:** PhET: States of Matter]	pressure and temperature	
QP8. Explore the solid-liquid phase change for water and estimate the melting point of water in the simulation. Why is it so difficult to get a precise figure? **[Simulation model:** PhET: States of Matter]	Physical properties of water, breaking the intermolecular bonds	9
Heat		**N=17**
QP9. You may have noticed that metal objects often feel colder than plastic or wooden objects that are at the same temperature, so why do they feel different? [**Video:** Misconceptions about temperature]	Heat conduction	17
QP10. How does heat move from one material to another? Explain in molecular terms. [**Simulation model**: Mixing hot and cold]	Heat transfer	14
QP11. Carefully compare each conductor and analyze all of your readings. Which conductors allows the solids to reach equilibrium fastest? [**Simulation model:** Heat conduction]	Heat conduction and thermal equilibrium	15
QP12. Why is heat transferred more quickly in solids than in gases? [**Simulation model:** Heat conduction]	Heat transfer	11

The above table illustrates that QPs were useful to scaffold students' interactions and investigation of the targeted concepts. Two questions, QP4 and QP7, did not work effectively to prompt student investigation of the concepts. QP4 asked students to observe how the hydrogen atoms interacted with the oxygen atoms in water molecules. A multiple-choice question (MCQ) was posed at the end of the investigation to check whether students visualised it correctly in the simulation. The following *table 5-10* shows the findings from their responses:

Table 5-10: Students' responses to QP4 (MCQ)

Question	**Responses**	**N=13, total number of students answered**
		Frequency of selection
Which of the following describes a hydrogen bond?	The bond between hydrogen and oxygen within a molecule of water	7 (54%)
	The bond between two hydrogen atoms within a molecule of water	2 (15%)
	The bond between hydrogen in one water molecule and hydrogen in a different water molecule	0 (0%)
	The bond between hydrogen in one water molecule and oxygen in a different water molecule [This is the correct answer]	4 (31%)

The above data show that more than half of the students still held misconceptions about hydrogen bonding even after interacting with the simulation model where they were visually experiencing the making and breaking of the hydrogen bonds. Only four students were able to choose the correct answer. This finding highlights the importance of providing more specific instruction to focus on the infinitesimal happenings during the simulation activity. QP7, another source of difficulty for most students, asked them to set up the experiment in the PhET simulation by controlling the volume and temperature to see the corresponding changes in pressure. Students found it difficult to investigate the concepts. A student's comment about this issue provides a possible explanation:

> I don't understand the pressure as much as I do things with the temperature. I do little, but I feel like there was on that too many concepts, you know, happening in the same simulation… Maybe I had too many options or I did not know really which way I direct myself to look into... like, I was felt just like that there was too much to try and like regulate here and there and did not know what to look at. You know you just playing around with looking all things happen, but I didn't actually learn very well from that simulation. [PHSEM104]

The above comment raises the issue of the effectiveness of the information rich simulation interface in a self-directed environment. As it was necessary to apply several concepts in concert, that is, volume, temperature, and pressure, the student found it difficult to process and synchronise all the concepts. Therefore, the complexity arising from the information rich environment appeared to be a contributing factor to the stumbling block experienced by some students in the self-directed environment (Koh et al., 2010), especially when they were required to look closely at the minute connections and apply skills relating to the concepts.

In brief, QPs accordingly played a vital role of engaging most of the students with the activity. Well-constructed question prompts elicit a desire in students to learn (Edelson, 2001). They facilitate students in performing investigations to answer such questions (Krajcik et al., 2006). However, as observed, they did not achieve the desired scaffolding outcomes in all the cases. In brief, the findings of this study revealed that QPs were dependent upon various factors to direct students to inquire into the specific concepts. These factors were:

- Sometimes, even in the simple simulation interface, learners, who preferred symbolic representations, (e.g., reading texts), found it difficult to follow the QPs. Therefore, the questions failed to prompt them into pursuing the conceptual inquiry. Consequently, they asked for more specific instructions. Example: "*I did not realise you can click on the things make thing happens. I did not know that. Usually, I am not a computer person, a book person.*" [PHSEM206]
- The complex interface of the simulations caused difficulties for many students. QPs, without specific instructions, did not assist adequately. Example: "*When I judge the variables, they don't actually say anything that I am doing. So, I need to do every single thing. If I need to understand, I think it will be better if someone will there to guide.*" [PHSEM205]

- The above data suggest that there might be a need for a more individualised instructional setting as the absence of this degree of guidance affected students' performances in the self-directed environment.

5.3.3 Hints and highlighted words

Hints and highlighted words have been found to be a useful scaffolding tool to facilitate students' inquiry process. Research has revealed that there are qualitative differences amongst students' thinking as they endeavour to understand any concept (Entwistle, 2000; Marton et al., 1976). This can mean in some cases that unstructured learning may occur frequently in the self-directed environment. To minimise this potentially random student behaviour, *Hints* (sometimes in the form of 'Check Concept' buttons) *and highlighted words* were used to facilitate them to think and head in the right direction. The *table 5-11* below illustrates some findings about this scaffolding technique.

Table 5-11: Subthemes that emerged related to hints and highlighted words

Theme: Hints and highlighted words facilitate students' learning		
Subthemes	**Examples of student quotes (from interview)**	**Findings**
Hints and highlighted words to facilitate students thinking in the right direction	*I still was not sure which one of these are water and which one of these are oil. By reading these stuff (from hints), I understood more, and this is when I got back on track.* [PHSEM101] *I found that when I was looking at the other ones, where there was a specific instruction it was better on the words with colours or bolded or something. So, it is specific. You need to look at this before you move on.* [PHSEM101] *Instead of having it in the same sorts of writing, if it stands out and grabs the attention then, yeah, I will read it.* [HTSEM105] *I really liked these (hints), the extra information in the background.* [HTSEM101]	Enhance understanding Guide to right direction Provide supporting and necessary information Provide specific instruction Help keep attention to the keywords Help keep attention to the important events Offer comfort during the inquiry process
Hints and highlighted words helped students to understand the concepts	*Yes. It ('Check Concept' button) is very useful. Once I read this then I looked at it and could see where like how tightly the water molecules were.* [PHSEM103] *I think after I did the simulation and exploring the hint button I did realize what it was.* [PHSEM105] *I definitely feel comfortable with the blue little writing down the underneath, I found that really helpful.* [PHSEM101]	

The above statements revealed that *hints, concept check* buttons and *highlighted words* had played an important role in helping students to engage with the activity. Students also reported *in the table 5-11* that colourful and highlighted words minimised the chance of skipping important concepts. Beyond making learning easier and more comfortable, they were useful because they helped students to head in the right direction. These findings point to the need to facilitate students' visualisation skills as this prompting offered them a genuine opportunity to understand the concepts.

5.3.4 **Instructional guidance**

The key procedural scaffolding techniques used in this study were the various modes of written instructional guidance that were implemented to help students interact with the activities across the modules. Instructional guidance was provided to various degrees: strong, moderate and open/minimal. This study found that a strongly guided activity was the most effective scaffolding technique to facilitate students' engagement in the self-directed environment (Appendix C, data set 2 and 3). The following table *5-12* illustrates the effectiveness of different instructional settings:

Table 5-12: Effectiveness of different instructional settings (Source: Appendix C, data set 2 and 3)

Theme	**Subthemes**	**Number of students**
Instructional guidance facilitated students' engagement	Strong guidance facilitated students' engagement [N=21]	13 (62%)
	Moderate guidance facilitated students' engagement [N=23]	12 (52%)
	Open-exploration/ minimal guidance facilitated students' engagement [N=24]	6 (25%)

The above data confirmed that guided activities (either strong or moderate) facilitated students' engagement for more than half of the students. In contrast, open/minimally guided activity was perceived by only a few students to being effective. In these cases, the students felt that guidance in the form of direct instructions was unnecessary, with the simulation itself being sufficient incentive to lead them into the exploration. This suggested that a type of implicit guidance met their requirements adequately; so, these students found the guidance to be redundant, as they followed the consequences of the events happening in the simulations. The affordances of the simulation environment and different embedded controlling parameters and their functions led them to explore without further scaffolding. This exploration was self-initiated and sustained, so these students did not feel they were being guided. A student fitting this category explained in the interview:

> I think simulation itself can guide. The whole idea is kind of like, just a make your own way through this sort of things and specially play around with all the concepts. Manipulate all these things and answer the questions, do what you want... you can do the most things you really like, kind of get yourself involved and learn in deep level sometimes. [PHSEM207]

This student believed that the incentive to engage in a manipulative process of exploring the simulation was productive and effective. An open activity that invited the students to, "*do what you want"* was appealing for eliciting engagement. This type of open-ended activity might help students to engage at a deeper level especially when students are interested in working independently. Also, there were students who felt that excessive instructions and information may not be suitable in an exploratory learning environment. Examples:

> If there was a lot of things to do and if there was a lot of instructions, I think, it put me off." [HTSEM109]

I did not need personally any explanations. I think, if there were any explanations, it would have stuck me from understanding some other qualities which actually showing visually here. [PHSEM207]

The purpose of open exploration was to enable students to investigate the concepts independently, as depicted by the above examples. However, this did not work in many cases. Many *s*tudents found it difficult without guidance to explore and engage independently with the learning module. A few informative quotes from students' interview are shown below:

It is not clear about the objective of this simulation. There should be clear instructions of the activities with the simulation. [HTSEM206]

There are some parts, need to do some activities but there are not enough instructions for me. So I am struggling there. [HTSEM204]

The simulation was pretty hard to understand. Because I had to play around the things myself, and it will better if there somebody actually voicing over or actually explain to you. [PHSEM205]

If there was nothing to tell me what to do, then I probably would have stumbled around for a bit. So, if there are instructions on how to open it, then it would be fine. [HTSEM205]

The above data clearly revealed that unguided activities did not help students to meaningfully engage and explore the activities. For more specific insights on this issue, the following example provides a "window" for understanding a student's behaviour in an unguided activity. In the thermal expansion simulation (hSim3) of the *Heat* module, minimal instruction was strategically given to heat and to cool down the system so that students might explore the simulation independently. While interacting with the task, the student [HTSEM103] only increased the system's heat, overlooking the use of the 'Cool' button to reduce the temperature of the system for further investigation. When asked why he did not cool down the temperature, the student reported: "*I just heated it all the way to see how to get it overflow. Because that was my intention. I did not think to cool it''* [HTSEM103].

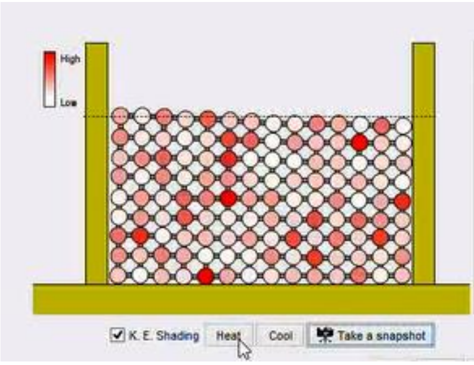


Figure 5-1: Thermal expansion in hSem3 simulation model

The behaviour of this student was both beneficial and detrimental at the same time. On the positive side, the student had the freedom to explore that which was appealing. In this specific example above, we see that the student wanted to experience the extreme heat condition of the object. It was interesting that the student intentionally overheated the object to learn what would happen in extreme conditions. This aim consequently enabled the student to experience new phenomena relating to molecular behaviour, possibly leading him to construct new knowledge. This is an informative example of inquiry learning in an open-ended environment. In such a space, the student could enjoy his interaction with the simulation by inquiring into new phenomena in a way that was appealing to him. The end result could be the product of an experiential learning experience.

Other studies also reported to some extent that students did make productive choices in many cases, and the simulation provided these students with many learning opportunities (Podolefsky et al., 2009). However, it might also lead to unproductive results. In this case, the student left the cooling down feature of the simulation, and therefore several important concepts were potentially unexplored. For example, students might observe the molecular behaviour at a low temperature, especially at the absolute zero temperature condition of the system, an opportunity in the real world that is beyond real experience. So herein resides a pedagogical conundrum. Through self-exploration in an open inquiry, a student might experience and construct new knowledge, but at the same time, it might not produce the anticipated learning outcomes. Rather, as other studies reported, it is likely that an open exploration of a complex environment may produce a high cognitive load for the novice learners that is detrimental to learning (Paas et al., 2003; Sweller, 1999). It also raises the concern that students will be led to incorrect conclusions if left to find and use educational resources on their own (Podolefsky et al., 2009). Therefore, a systematic instructional approach might, in balance, be adopted to help most students to explore the simulation, enabling productive learning during the inquiry process.

The data of this study showed that under a strongly guided condition, students' engagement and interactions were found to be high, indicating that instructions helped them to undertake a meaningful exploration. The following *table 5-13* illustrates some examples in favour of the strongly guided activity:

Table 5-13: Examples in favour of the strongly guided activities

Subthemes	Examples of students quotes (interview)	Findings
Strongly guided	*I follow the instruction. I went up and down few times to check this. The non-polar molecules start kind of moving away a little bit more. They break their bonds and they start to make separating whereas the polar one just stays because they are all tightly packed.* [PHSEM103]	-Improves visual ability -Supports meaningful exploration -Helps to understand the polar-nonpolar bonds
	I think it's really important to have textual instructions. If something you don't understand, it is there in front of you and you can work way through it. [HTSEM101]	-Supports meaningful exploration
	Instruction says that run the model for a while and observe the bar graph on the right. So, sort of just waiting to see if anything was going to happen. And, yeah, I did notice that the temperature was decreasing when the cover was removed as the molecules start evaporating. [PHSEM105]	-Improves visual ability -Supports meaningful exploration -Helps to understand the evaporation process
	The instructions said, see how quickly the heat is conducted from the hot object to the cold object and like from knowing that from	-Supports meaningful exploration

	the instruction then you are going to do with the activity clearly. [HTSEM103]

The above data provide evidence that when students followed the instructions, their visualisation skills, perceived understanding were improved and thus a meaningful exploration occurred. Also, instruction encouraged students to focus on the important content thus reducing the chance of missing important aspects of the simulation. This is because, in the simulation environment, instructional support enables the students to acquire skills independently and reduces the complexity of the simulation to a level supportive of learning (M. Yaman et al., 2008).

The above discussion contributes positively to the vast field of literature where researchers argue for the importance of instructional guidance in inquiry learning (R. Clark et al., 2012; Kirschner et al., 2006; Luo, 2015). Specifically, the data reveals that instructional supports were found to be the key element of the scaffolding strategy to facilitate students' self-directed learning in the inquiry process. However, as few students preferred openness in the activity, the data also suggest the importance of personalised instructional guidance in online settings. This highlighted issue suggests that further research into the context of self-directed online learning is warranted.

5.4 **Explain phase (E)**

Concept Check Questions (CnCQs) and Confidence Check Questions (CfCQs) were employed in the *Explain phase* to facilitate conceptual and metacognitive scaffolding functions respectively. Once students explored the activities through the simulations and videos and gained an understanding of the process, CnCQs and CfCQs were posed to interrogate the students' understanding of the concepts. Examples of CnCQs and CfCQs used in this study can be found in *Chapter 4: Learning Modules Design; section 4.6.3 and 4.6.5*. The following sections discuss the key themes and subthemes that emerged in relation to the scaffolding functions when students were interrogated with the CnCQs and CfCQs.

5.4.1 **Concept Check Questions (CnCQs)**

CnCQs were used in this study as a scaffolding element to support student inquiry enabling testing to ascertain what concepts had been learned and applied in order to address the problems experienced by students in response to a given question's scenario. Students were required to write down their understanding in a text box provided and press the submit button once they had completed their explanation. This strategy allowed students to participate in the learning process by allowing them to explain their acquired or intuitive knowledge, and their critical thinking they may have employed in the process.

Table 5-14: Emergent themes and subthemes in relation to CnCQs

Key theme	Subtheme
Concept Check Questions (CnCQs) conceptually scaffold students thinking to facilitate their cognitive engagement	Student inquire and identify the key concepts related to the problems Student apply the concepts to solve the problems

To understand how CnCQs facilitated students' cognitive engagement, the following examples were extracted from students' written responses.

Table 5-15: Role of CnCQs to facilitate students' cognitive engagement

CnCQs	Students' written response	Findings
CnCQ4: 'Water molecules do not move in the solid (ice)' - Do you agree or disagree? Explain.	*Disagree. They still move but not fast enough to break their bonds.* [PHSEM103] *Disagree. The molecules within a solid state vibrate! They may not move freely like water, but they are still moving small amounts.* [PHSEM104]	-facilitate students' cognitive engagement by committing them to choose an answer
	This is incorrect, molecules in solids do move, however, they do not move as rapidly nor, do they spread like that of a gas due to their inability to move. This is due to the restriction they have due to the bonds with other water molecules. Their movement never stops. [PHSEM101]	-facilitate students' inquiry process by committed them to justify their position
CnCQ9: A vacuum flask (Thermos flask) is a double-wall container with a vacuum between the two walls. How does the flask keep its contents hotter or cooler than the outside air? Explain your answer using kinetic molecular theory.	*Since a vacuum has no particles in it, it stops conduction by allowing the particles to collide, so if there are no particles to collide with, heat won't be transferred, and the temperature will remain constant*. [HTSEM206] *Vacuum does not allow for any conduction of energy as it does not contain any air particles. Thus, the content of the flask remains hot because it is unable to transfer the heat anywhere else ...* [HTSEM103] *… The effect of the air on the outside of the container is kept away from the contents by a layer of air being between it and the inside layer of material which is touching the liquid.* [HTSEM107]	-facilitate students' reasoning through skills and through their explanations -facilitate students' application skills

In the first item (CnCQ4) students were required to agree or disagree with the statement, which is a form of scaffolding where students were required to prefer one option over another. It guided students to commit to an answer and justify it. It required a cognitive response necessary to answer a question even when the respondent's ability and motivation was low (Tourangeau et al., 2000). Students need to comprehend the question, retrieve relevant information from memory and integrate the information into a decision. The above example revealed that students were committed to opting for an answer by showing disagreement with the statement. Thereafter, PHSEM101 explained the reason by indicating the strong molecular bonds (intermolecular attractions), while PHSEM103 mentioned the issue of molecular velocity, which is related to the molecules kinetic energy. In contrast, PHSEM104 failed to mention any reasons for such behaviour. Overall, the data revealed that they understood the concept that molecules are vibrating in solid states, which supports the hypothesis that these types of questions are useful in the self-directed online learning.

The CnCQ9 also impacted strongly in improving students' reasoning skills. For example, in CnCQ9, students demonstrated sound conceptual understanding. The first two students HTSEM206 and HTSEM103 understood the problem and addressed the reasons correctly. The above data suggest that CnCQs, as inquiry questions, help students to think and aim to achieve conceptual understanding (Kawalkar et al., 2013). On the other hand, HTSEM107 misunderstood the concept of vacuum as he indicated that it contained a "layer of air". Referring to the data set 3, Appendix C, it has found that this student showed high persistence and have produced 1 systematic investigation with the simulation that deals with the vacuum space. This indicates that the student engagement was fairly high. Therefore, it could be said that this student produces an alternative conception even after high engagement with the simulation. This suggests that there were always a few cases where students developed alternative conceptions (sometimes misconceptions) during the learning process. The nature of these alternative conceptions and misconceptions might be explored in future research focusing on scaffolds that benefit the learner in the self-directed environment.

One notable finding common to all the questions was that students often failed to transfer and apply their learned knowledge to address the given problem implied in some higher cognitive level questions. It might be because higher cognitive questions place more demands on the learner (Kawalkar et al., 2013). Unsurprisingly then, many students failed to provide a reasonable answer to a higher-level question. One such question was CnCQ10: *What will happen to the hole in the iron plate, when the plate is heated, and why?* (adopted from IAMMIC-project, 2013). The purpose of this question was to assist the students to make inferences based on specific information they had learned to support their explanations. CnCQ10 is a higher cognitive question that required student understanding of thermal expansion relating to the circumference of an iron hole. The question was also formulated to promote improvement in their abstract thinking skills. It was relatively simple for them to conclude that the circumference of the outside of the iron plate had expanded, but this is not so basic when the inner hole was considered. Below are some examples of student responses:

Figure 5-2: Inner hole of an iron plate

> The hole will get smaller, the thermal expansion happens in all directions, both outward and inward. [HTSEM206]

> The hole will decrease in size as the plate is heated due to the atoms moving with more kinetic energy and requiring more space to move around in. [HTSEM101]

I think that the metal is expanding because the atoms are moving farther apart when they get hotter. The hole will become smaller in diameter when the plate is heated due to its molecules vibrating more. [HTSEM107]

In this problem, students explained the concept of thermal expansion by stating that when heated, molecules naturally spread out more, which is correct. However, they failed to rationalise and visualise correctly what happens to the inner circumference of the iron hole. All the students mentioned that the hole inside the iron plate would decrease in size, which is incorrect. Actually, the hole would expand. It was relatively simple to rationalise that the circumference of the outside of the plate expanded, but this was not so basic when the inner hole was considered. It is useful to imagine the atoms that line the edge of the inner hole (effectively a circle of atoms – see the diagram). If the distance between them increases, then the circle becomes bigger. In effect, the hole increases in size.

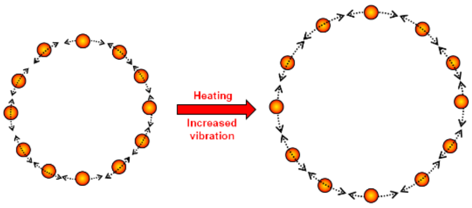


Figure 5-3: Thermal expansion to the inner circumference of the iron hole

This inability to transfer apparently well-established knowledge is something of a conundrum. It is suggested by Karpov (2003), articulating Vygotskian thinking that once scientific concepts are established, then this organized knowledge plays a mediating role in the development of problem solving skills, and so thinking becomes more "independent of their personal experience" (p.66). However, in itself scientific concept formation appears to be insufficient for applicative purposes; rather it is argued that procedural knowledge needs to be taught and implemented in tandem with concept development. Accordingly, Karpov (2003), recommended that the combining of conceptual and procedural knowledge led to "a high level of mastery, broad transfer, and intentional use by students" (p.69). However, as this is an example of higher order problem solving, further research is required to investigate whether it is simply the students' inability to transfer the knowledge or further scaffolding is needed in parallel with careful calibration of the instructions to support development of the correct mental model of the concepts.

5.4.2 Confidence Check Questions (CfCQs)

CfCQs worked as metacognitive elements in the *Explain* phase by providing the students an opportunity to reflect on what they had understood from the experience of solving the given problems. CfCQs were used after each CnCQ to make students aware of what they had written and to ascertain their degree of confidence in their understanding of the concepts they had learned. They were asked to rate their confidence level from 'very high' to 'very low' on a 4-point rating scale. This study does not focus on measuring what percentage of students selected High, Low etc., but rather explores how the CfCQs influenced students' thinking about their answers. It was found that the CfCQs were effective in helping students to reflect on their understanding and in supporting higher order thinking.

Table 5-16: Emergent themes and subthemes in relation to CfCQs

Key Themes	Scaffolding functions	Subthemes	Frequency of occurrences (student action) [N=30]
Confidence Check Questions (CfCQs) assist students reflecting on what they have learned	Metacognitive	Awareness of comprehension of the concepts	25
		Rethinking on the concepts understood	22

CfCQs were used to trigger the students' metacognitive awareness and to facilitate reflection on their understanding that was enlisted in answering the CnCQs. The data revealed that once students encountered the CfCQs, they became mindful of their explanation. The following *table 5-17* provides some of the students' quotes in relation to the two subthemes that emerged from the findings in connection to CfCQs:

Table 5-17: Examples that support the subthemes in relation to CnCQs

Subthemes	Students' quotes from interview
Awareness of conceptual comprehension	*Oh! At that time, I think I was 80% confident. I really believe this at that moment. Because when I think of temperature I just think like greater kinetic energy.* [HTSEM103]
	It is just how confidence I am feeling like as typing it in. Oh, yes, I know this! Or, is this what it is like! [PHSEM105]
	I was not very confident on the paper and metal one. Like from the previous video I was more aware that the metal removes the heat. [HTSEM105]
	And I was not confident about the vacuum one. Low confident. Like that, I know that there (in a vacuum) is no heat transfer. They just remain the same. [HTSEM104]
	I put High Because I think when I wrote it, I thought Oh Yeah, that's good. But, maybe this is not that good actually after I have submitted it. [PHSEM106]
	I have Low confidence. I did not really know the kinetic molecular theory. I was not too sure what that was. [HTSEM105]
	I want it like one in between (High and Low). I have the right idea but I am sure I didn't have the right terminology or the right way of explaining it. [PHSEM104]
Rethinking the concepts they learned	*When I put Low, definitely I want to learn more as well. If I put in High, then I want to sort of second guess myself and ask myself again, do I really think that I am good at it or something like that*. [PHSEM101]
	The questions at the end (CfCQs) force me to actually think about the topic of just, you know, supposedly learned about. [HTSEM102]
	I was not confident. I don't know if that would, because, the hot gas close to the cold gas, but then I thought somehow the hot molecules mix might with the cold molecules and become equal like that. [HTSEM104]
	I was confident that the hole will get smaller, but I was not 100% sure, like what's happening at the molecular level. [HTSEM105]
	Low. Because I was tossing with both the idea. [HTSEM106]
	I think put Low confidence. Because I was thinking more in terms of high humidity saturating and then heating the cold mirror causing condensation. [PHSEM103]

The comments in the above table demonstrate that when students encountered the CgCQs, they were prompted to reflect on their thinking and action, that is, whether they had responded correctly and in sufficient depth. The questions improved the students' awareness and higher order thinking about the concepts they had understood, and in the process helped them to rethink their initial understanding.

Still, this *Explain* Phase did not sufficiently satisfy the students' demands as there was no confirmation whether their conceptual understanding was right or wrong. Students were curious to obtain feedback, that is, to see if their response was correct, or incorrect, and to understand why it was so. Students were required to move to the next stage to obtain the feedback they desired. This was the last stage, namely the *Evaluate Phase* of the learning modules.

5.5 Evaluate phase (E)

Introducing the evaluate phase was a deliberate strategy in the scaffolding design of this study to engage students with their own thinking and facilitate them to reflect and evaluate their understanding. The following *table 5-18* represents numerous students' quotes that show how synchronous feedback was involved in helping the students evaluate their understanding.

Table 5-18: Students' quotes on the effectiveness of the Evaluate phase

Key theme	Frequency [N=30]	Examples of students quotes	Findings from the quotes
Synchronous feedback helps student to clarify and evaluate their understanding	26	*If I did not get the feedback and if I did not know the answer I would just carry on with not really understanding the concept. But because it gives you the opportunity to answer and then give feedback on it, yeah, I think that is really helpful.* [PHSEM103] *And I did not understand until I read the feedback. I have not connected until I got the explanation. I thought maybe they would different. Now I fully understood, what was occurring there with the molecules and how the temperature is going down.* [HTSEM107] *Towards the end when I started getting the feedback, I think I understood the concepts more.* [PHSEM101] *I like feedback. I think it makes understanding clear. The explanations are given are point-by-point, very straight as I work. And that something that I struggle in general, if I can get a really kind of drive explanation, I will appreciate that.* [PHSEM207] *I would like to get feedback, so I know if I am on the right track. So, there were a couple of*	-Feedback provides opportunity to clarify the understandings -Feedback provides clarification and helps students to make the connections between the concepts -Feedback improves engagement with the contents -Feedback helps to provide understanding of the concepts -Feedback makes understanding clear -Feedback removes hardship and makes the learning process easier -Feedback provides clarification of the concepts

	questions in there that did give feedback, then it explained why I would get the question wrong and why I would have got it right. I found that particularly useful. [HTSEM101] *I think some questions where no feedback was given, it does not tell me afterward whether I am right or wrong. It really has to get the feedback to know why I am right or why I am wrong.* [HTSEM106] *I don't really think I have got what was happening. But at the end feedback, I think, did clarify it.* [HTSEM108] *I found feedback is very useful. Once I read this then I looked at it and could see where like how tightly the water molecules were.* [PHSEM103] *I didn't realise that, and I haven't ever really thought about that, because in my mind the things obviously expand but, it's apparently not. Once I read the explanation, it was clear to me.* [HTSEM207] *The modules are self-regulatory because it just tells you what to do, you do it at your own pace. Especially it gives you the model answer or an explanation behind it.* [HTSEM206] *Learning with simulation, I guess, it's kind of doing the experiment but it's not so hard to set it all up like you actually get some real-time feedback and you get to see it yourself and draw your conclusions.* [HTSEM205]	-Feedback helps students to stay on the right track -Feedback clarifies the concepts and helps student to judge whether he is right or wrong -Feedback keeps students on the right track -Feedback provides clarification of the concepts -Feedback provides clarification on the concepts -Feedback provides clarification on the concepts -Feedback makes the learning self-regulatory -Feedback enables students to judge and draw conclusions

This data revealed that, in the self-directed online learning, synchronous feedback on students' learning helped them to evaluate, clarify, and confirm their learning. It not only provided them clarity about their understanding but also supported them through a systematic learning path so that they could proceed without direct supervision. Without the feedback, students found it difficult to know whether they were on the right track or not. Synchronous feedback made it easy for students to adjudicate their understanding, helping them to make connections between the concepts to create a more complete understanding. In fact, all the students stated that their preference was to receive feedback in the learning modules. Previous research also confirmed the importance of timely and frequent feedback that contributes to online learner performance (Goldsmith, 2014; Thiele, 2003).

Hattie et al. (2007) stated in relation to students receiving quality feedback that three essential questions needed to be resolved by students in their striving to achieve their learning goals: 'where am I going?', 'how am I going?' and 'where to next?'. van den Bergh et al. (2013) pointed out that the first question should address the learning goals. The synchronous feedback adopted in the current study essentially provided students the goals for what they were going to learn and thus addressed the first question proposed by Hattie and Timperley. van den Bergh et al. (2013) further pointed out that the last two questions should address what students need to know: how their current performance relates to the learning goals and what activities need to be undertaken to make progress. Synchronous feedback, as observed in this study, prompted students' awareness that their current performance (students' self-exploration and engagement with the activities) was on track (or not) thus enabling them to understand the concept. This eventually led students to answer the third question 'where to next' by referring students back to the activities for revisiting, re-exploring and re-evaluating their understanding.

While the *evaluate* phase has proved crucial to the cognitive development and metacognitive reflective process embedded in the core POEE scaffolding strategy which acted as the "backbone" for the online modules, it is apparent that many students required more explicit content feedback, located earlier in the strategic process, such as inquiry questions, hints and instructional guidance used in this study. This aligns with the second question that Hattie et al. (2007) cite: "How am I going?" It seems that feedback at different stages of the modules has the ability to meet different psychological and educational purposes. Therefore, feedback is conceptualised as many faceted and a multi-dimensional strategy that is indispensable to students' achieving understanding of their current learning status.

To summarize, students found the feedback feature very useful during their activity. However, a small number of students suggested that the feedback should be very concept specific as it was perceived that excessive information created cognitive overload and thus detracted from their achieving the desired learning outcomes. Therefore, it is crucial that feedback should be well-crafted and concept specific, qualities, which not only help students to clarify their concepts but also to serve as an instructional tool in the learning process. It is possible that in the development of modules in the future need to consider the nature and positioning of various forms of feedback in relation to the strategic stages.

5.6 Issues found

This study utilized various scaffolding techniques and procedures to cater for the students' needs in the online environment. Due to student diversity, there were some issues observed in different dimensions. The following are the notable issues observed in this study and are discussed in greater depth below:

- Technical difficulties
- Difficulties in following the instructions
- High Initial investment of time in engaging with the simulations
- Difficulties in the execution of the simulations

- High workload

Technical difficulties: Several students found it difficult to adequately interact with the simulations regardless of the instructional guidance. As a result, meaningful and productive exploration of the simulations was not undertaken by these students. The following are two examples of the data illustrating the difficulties experienced:

Example 1: Simulation model, hSim1*: Mixing hot and cold chamber* with guided instructions in the Heat module

An example of observed student behaviour: a student took 4.40 minutes just to run the simulation successfully. During this time, the student clicked on the snapshot button several times, read the instructions, and clicked on the different sections of the simulations. After that, the student was able to click on the play button to run the simulation.

Reasons: It was found that the student had a lack of prior experience, which meant that he encountered difficulties in following the instructions in the self-directed environment.

Example 2: Simulation model, pSim1: *PhET simulation* with instructions to 'save and run' in Phase Change module

Observed Student behaviour: A student was able to run the simulation after two unsuccessful attempts. This simulation required the student to download and save the Java applet first. The Java applet took some time to load, and required permission from the user before running the simulation model could occur. Further confusion emerged when the simulation model departed from the open window and then appeared in a different window. In reference to this, the student stated:

> It was just confusion because I was expecting all of the things here set up to open up some programs, usually, the diagram is coming in web pages, oh wait, should that be happening… it was just going to java in different tabs. [PHSEM207]

Reasons: the student had to face complexity in different dimensions in order to run the simulation. From the student's perspective, an increase in workload by running and saving the simulation and opening it in a new window created unnecessary complexity.

Difficulties in following the instructions: This was found to be an important issue in the self-directed environment. Many students demonstrated difficulties in following the instructions irrespective of their background.

Case example: In the 'phase change' module, students were instructed to click on the 'run' button and then click on the 'remove the cover' button in the 'evaporation' simulation model to experience how evaporation occurred. These instructions were supposed to help students to explore the simulation in sequence and to assist them in understanding the concepts. However, in several cases, students found it difficult to follow the instructions adequately and therefore their initial time investment was longer than might have been expected. A student with such difficulties replied:

> Yeah, I did not read it properly. So, I could not remove the cover because I was clicking the cover button, not remove the cover. I always look at some things first and then read the instructions. But if I feel I can know what I am doing, I don't read the instructions, which is really bad in everything. And I do need to change it. Yeah, I should read the instructions first. Actually, if you find something, you grab it then move it off. So, I was always trying to drag it off... I guess it is just my way learning. [PHSEM104]

This student further reflected: "It is definitely good for self-learning. I should read the instructions most definitely. Yeah, it took a while to understand. And then I read the bottom of the simulation... Oh, I was so stupid. It's been there for a long time..." [PHSEM104]

Students thought that even if it took a longer time, exploring in the self-directed environment extended the opportunity for learning in different dimensions.

Reasons: Students revealed tendencies to skip reading the instructions due to their overconfidence in their ability to learn independently. There were also some other reasons implicated for the difficulties experienced that emerged regarding problems in following the instructions; these are discussed in the next chapter (Chapter 6: Student Engagement).

High initial investment of time: As a consequence of technical difficulties, several students spent a protracted period of time reaching a point of understanding while interacting with the simulations. Therefore, the time available for them to understand the contents and concepts was reduced.

Case example: A student exhibited an initial problematic behaviour with the PhET simulation and took a prolonged time to become involved. A question was asked about the issue that emerged during his initial investment to learn the PhET simulation model. He replied:

> I remember I think I am trying to move it (lid of the container) up. Whenever I moved it up I saw the cursor goes, oh, ok and I lost it. And I could use that. Also, it took me for a little while to realize how the pump work as well. [PHSEM207]

This student was unsuccessful in operating the container's lid. He saw the cursor change when it hovered over the lid, which implied to him that he could use it. However, he was unsure about how to do that, so he tried to move it up. Whenever he moved it up, he saw that the cursor was not going to lead him to a result. In addition, it took a little while for him to realise how the pump worked as well.

Another example where a student commented on how he invested initial time to understand the simulation: "It took me a bit of time to figure out how to work with the play (button) and then pressing the heat (button) for a long time to get the temperature up." [PHSEM103]

Reasons: The students were involved in navigating their course through a rich and complex simulation model. Sometimes the behaviour of some features of the simulation misled students. For example, one student understood that the lid had some function, because whenever he moved the cursor on it, he found that the cursor's appearance changed. So, he tried to explore it by moving the lid up. This move indicated that the student wanted to open the container; however, the lid was designed to explore the concepts of volumes and its relationship with pressure and temperature of the container by moving it down. So, it required the learner to move the lid down to the container to decrease the volume and to see the related changes in pressure and temperature. When students tried to move the lid in the opposite direction, that is, to move the lid upward to open the container, nothing changed. Consequently, the students gave up exploring its use. However, through continual exploration students found how other features of the simulations worked. Through some features, such as the functions of the 'pump', students were required to explore their use a few times to understand their purpose. This indicates that, even for a strong visually oriented learner, implicit guidance may not work successfully in the self-directed learning environment. It may require some external guidance for students to work with them effectively, and for a longer time, in order for them to understand how they worked properly.

Difficulties in the execution of the simulations: As a consequence of initial difficulties, some students could not utilize the simulation features properly. They did not even use the most useful buttons and therefore could not demonstrate the expected behaviour with the simulation model even after clear instructions were provided.

<u>Case example:</u> A student interacting with the *Dipole-dipole and London dispersion attractions* simulation model in the Phase change module. The student did not use the most important button 'viewing mode' of the simulation. When asked about this in the interview, the student stated:

> Because these white little circles (viewing mode buttons) look sort of almost the same colours as the grey background. I think it may be the grey background, maybe the small writing. I just completely missed out. I was more focused on the reading. So, I did not really focus on the viewing mode buttons. I did not even read the title either. So, may there are too many things in that space. And also, for the grey background, you could see the options to choose. [PHSEM101]

<u>Reasons:</u> Students' visual inability to differentiate the simulations features due to the rich and complex simulation environment

Rich and complex environment creates high cognitive workload: A simulation should appear with a simple interface, as it gives students the opportunity to manipulate the simulations for the investigation without overwhelming them.

Example: When a student faced the PhET simulation, he found it full of rich information, buttons and features. The student stated:

> More features will definitely make it more complex. But I think, if you could add more manipulative tools in a functional way so that you are not crossing the threshold, otherwise, ok, now I am lost. I mean if there are so many buttons, then which ones should be focusing on more than others? If you could do so on a really functional way for the sake of student so that they can learn very effectively then it would work. The key is not to kind of drown them in different options, you know. [PHSEM107]

Though this student wanted to manipulate options in the simulation, he believed that the options should be kept relatively simple. More features brought more complexity. Manipulative features were recommended but these should be user friendly, in order to minimise students feeling lost in the maze of features.

Reasons: Rich and complex simulation interface. Also, the lack of prior experience might have contributed as a hindrance for productive exploration.

Simulation can create misconception: In a particular situation in this study, it was found that when a student did not wait for sufficient time after executing a function of the simulation, he failed to experience the expected behaviour of the simulation model. This led him to a misconstruction of knowledge about the perceived situation contributing to the development of misconceptions.

Examples:

Simulation 1, pSim3 - Separated oil and water simulation model: After mixing the water and oil together students should wait for a sufficient time to observe that the oil and water are separated.

Simulation 2, hSim1- Mixing hot and cold chamber: After heating or cooling a chamber, students should wait for some time to see thermal equilibrium; otherwise, the student will not see the equilibrium conditions.

Reasons: When students do not follow the instructions diligently then their partial knowledge might bring some unexpected results and create misconceptions. In this aspect, the video is preferable because it gives accurate information, and there is little chance of forming misconceptions.

5.7 **Conclusion**

The findings in this chapter confirmed that the addition of the '*evaluate (E)*' phase to the original POE model could be an effective scaffolding strategy for online learning in the absence of direct teacher supervision. The key feature of the *evaluate* phase was synchronous feedback, which contributed significantly in helping students to clarify and evaluate their understandings. From a constructivist perspective, synchronous feedback helped students to construct knowledge by reconciling their prior understanding gained through their own observation and experimentation with the information they received from the feedback (Lou et al., 2003).

The findings from this chapter strongly suggest the importance and integration of multimodal scaffolding through efficient design and integration of the POEE, MERs, inquiry questions and instructional supports. Using multimodality as a scaffold gives students the opportunity to access and understand the given problem situations or complex ideas in multiple ways (Boche et al., 2015). This is particularly important in the self-directed learning situation given the absence of teacher support. The affordances of a multimodal scaffold can help students apply what information they gain and thus help them develop more sophisticated thinking (Boche et al., 2015). Therefore, it is argued that multimodal scaffolding was required for the students to secure success in a context where no interpersonal guidance was offered.

Despite the advantages of scaffolding, there were problematic issues that hindered online learning and proved to be detrimental to some students' learning. These problems collectively suggest that learning modules need to be developed and scaffolded, that they be personalised, and considerate of the individual learner's background. Towards this end, the following issues need to be considered:

- Students' prior experience with the online environment
- Students' visualisation skills
- The problems created by the rich and complex simulation environment.

This means that the design of the simulation modules requires careful tailoring to ensure that all students receive the most effective scaffolding guidance for their learning. The implication of this study is that the findings can contribute significantly to the development of learning modules to meet the demands of the ever-changing online course curricula.

Chapter 6
Student Engagement

6.1 Introduction

This chapter outlines and discusses the findings relating to three aspects of student engagement in the online environment, namely behavioural, cognitive and attitudinal engagement. The data and results pertaining to student engagement are discussed in the context of the absence of an “on the ground” teacher or peer support during the student activities. This meant that students experienced autonomy during the learning process. It was found that student engagement was affected by the workload and demands of the learning activities, the level of embedded instructional support, the ability of students to follow the available instructions, and the benefit of prior experiences, in particular through preferences for MERs, and so forth.

6.2 Behavioural engagement

In this study, behavioural engagement refers to student interaction and participatory involvement with the online learning modules. It encompasses students’ doing the allocated work while revealing the degree of effort they invested towards task-completion, an element of which required following instructions. The themes and subthemes that emerged from the data of the students’ interactions with the activities across the modules are recorded in the table below.

Table 6-1: The themes that emerged related to students’ behavioural engagement

Theme	Subtheme
Engagement with the allocated task	Demands of the activities affect engagement level
The degree of effort students put into the task	Instructional guidance affects students’ persistence and systematic investigation
Students’ task accomplishment	Workload affects students’ task accomplishment with the MERs

6.2.1 Engagement with the allocated task

This study, in the absence of teacher and peer support, provided a self-directed constructivist environment that facilitated learners’ autonomy across the activities. Nevertheless, in spite of the lack of interpersonal guidance, the data revealed that the average engagement time was found to be satisfactorily high. For example, as shown in the following table, the average engagement was timed at 44 minutes in the *Phase change* module and 51 minutes in *Heat* module; of note, is that the modules were designed to occupy students for about 50 minutes.

Table 6-2: Students engagement facts in *Phase change* and *Heat* module

Measurement	**Phase Change Module Duration: 50 minutes**	**Heat Module Duration: 50 minutes**
Highest individual engagement time recorded	1 hour 22 minutes	1 hour 30 minutes
Lowest individual engagement time recorded	16 minutes	23 minutes
The average engagement time recorded	44 minutes	51 minutes
Students' high and low engagement data	**N= 13**	**N= 17**
Number of high engaged students	8	13
Number of low engaged students	3	1
Number of students who engaged moderately	2	3

More details about students' time on task in simulation and video activities can be found in *Appendix C, data set 1*. Each learning module is comprised of several individual activities with students' engagement time varying across the activities. A standard average time was set for each activity; this was calculated by observing all students' interaction with the activity and taking the mean value of their total time. For example, in a simulation activity, it was calculated that within the standard time provided, a student could explore all the possible functions of the simulation model. When student engagement time equalled or went beyond the set standard time, the students' engagement was defined as *High*. In addition, a minimum threshold time was set in which a student could explore at least half of the functions of the activity. Students who were engaged below this threshold were considered as *Low* in engagement. Thus, *Moderate* engagement was recorded as midway between *High* and *Low* engagement. Similarly, in relation to the video activities, I categorise students' engagement as High or Low based on the criteria: whether student sees the full video; skips any part of the video; pauses the video to concentrate more on a particular moment; or rewinds the video etc. to measure their engagement. When students viewed a full-length video without skipping any part of this requirement, this was considered to indicate *High* in engagement. It was considered

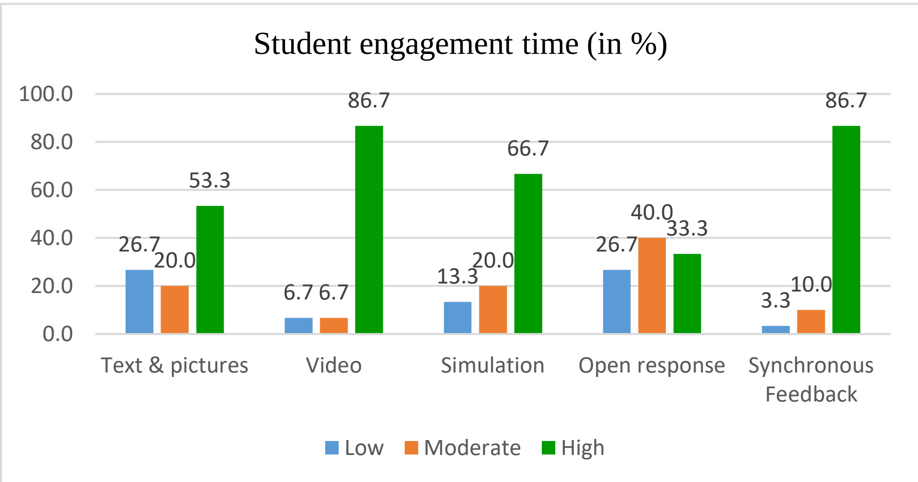


Figure 6-1: Graphical representation of student engagement across the activities

Moderate if students were engaged for at least half the length of the total video time. Any students who engaged for less than half were considered as *Low*. Similarly, in relation to other representations such as open responses (inquiry questions), images and for the synchronous feedback, *High*, *Moderate* and *Low* time engagement were defined. The following figure 6-1 represents the overall engagement level for all 30 students across the five different activities in the two learning modules. The above figure 6-1 illustrates one interesting finding that students' average engagement time was higher in video activities compared to the simulation activities. In investigating why the video activities attracted higher engagement time in the learning modules, the following findings were revealed:

Table 6-3: Student explaining the reasons of high engagement in video activities

Students' Comments on Video	**Findings**
- *I think naturally anyone is happy to see the videos. It explained well, and it helped my understanding of the structures of the water molecules in different phases more clearly. [PHSEM206]* - *This video is very interesting. It gives me motivation and keeps my concentration. It addresses my misconceptions of the daily life. This is like interacting with and asks a different kind of people. It is more like watching a show and at the same time gaining a knowledge… [htsem202]* - *I prefer video to the simulation because it explains the things very short way. In the simulation, there are some parts require doing the activities but there are not enough instructions for me. So, I am struggling there. [htsem204]* - *I liked it. I thought it is interesting and abrogating misconceptions. The video is good because it is simple for the ordinary people because it explains the things in natural settings and not in the laboratory settings. [htsem207]* - *I love the videos because it does not require so much input on your part. But you can just sit back and take it all visually. [htsem102]* - *The video is good because it explains the things with precise information and focuses only on a specific concept. [PHSEM103]* - *I prefer probably the video. Because it is more real life, it is more relatable. I think if you have no background understanding, then the video helps because it explains the things. [htsem109]*	- The videos are well-explained - The video is interesting because it is like watching a show. It interacts with the people and asks about the misconceptions. - The video takes less time to explain the concept. - The video talks about a specific concept. - The video explains the things in natural settings and not in a simulated environment or laboratory settings. - It does not provide much information rather very specific information has been conveyed - Video does not speak about a volume of information, so student can concentrate better - The video directly addresses the misconceptions from daily life that creates student interest - The video does not require to give input from student side i.e., not interactive

The data revealed that the nub of higher student engagement with the video is that overt construction as expressed in active participation during the learning process was not required. Indeed, active participation and manipulative effort in response to the video was minimal compared to the engagement required in the simulation activity. Simulations are embedded with enriched information and require interaction to unearth the content. Simulations require students to involve themselves in an exploratory process; active participation and manipulative effort are indispensable in the simulation activity. In contrast, the video engaged students, albeit passively, which in turn caused students to experience low interaction and thus low manipulative effort during the learning process that ensued. Moreover, the videos directly addressed possible student misconceptions, so the students had the opportunity to reconceptualize their understandings. This finding also supports the related findings, discussed in section 6.3.1, in which it was discussed why students preferred videos to simulation activities.

Students also demonstrated high engagement with synchronous feedback activity. They found it useful as it clarified and enhanced their understanding of a given problem. The following table 6-4 shows some of the students' comments about how feedback influenced their engagement and learning process.

Table 6-4: Feedback influencing students' engagement

Students' Comments on Synchronous Feedback	**Findings**
When I got it wrong, I went up again (to the simulation). Then I cooled it down. OK, now I understand how the intermolecular bonds like just expand and contract. [HTSEM204]	-Increase student's interaction -facilitate deep exploration
I like feedback. I think it makes understanding clear. The explanations are given are point-by-point, very straight as I work. And that something that I struggle in general, if I can get a really kind of drive explanation, I will appreciate that. [PHSEM207]	-Increase student's motivation
Yeah, I do. I liked to answer, and I would like to get feedback on it, so I know if I am on the right track. [HTSEM103]	-Facilitate clarification on student understanding
It was good to have that feedback and the little video afterwards. Now I know why I got it wrong and I will not get it wrong again. [HTSEM101]	-Facilitate reflection and awareness
I was recalling the previous knowledge, so I choose the charged particle one. The feedback that was given from the wrong answer I think really did clarify what was happening. [HTSEM108]	-Feedback clarified what was happening
I like the challenge of having a question then not knowing the answer and then getting the feedback and then being able to think about it. The answer (in feedback) always seems so clear when it was given to me. It was like, 'Oh Obviously. Yeah, this is the one.' [PHSEM103]	-Facilitate engagement through the learning process -Provides motivation
If I did not get the feedback and if I did not know the answer I would just carry on without really understanding the concept. But because it gives you the opportunity to answer and then give feedback on it, yeah, I think that is really helpful. [PHSEM103]	-Remove misunderstandings and provide motivation

The above examples described how feedback helped students in their interactions and understanding by removing doubt, providing motivation and consolidating their learning. In several cases, as observed in the above table, students commented that feedback confirmed for them their degree of understanding, informing them whether they were on the right path or not. This meant that the immediate feedback confirmed or disconfirmed their understanding. It is clear that providing synchronous feedback potentially improves student engagement and learning in online settings, a finding supported by the research of Mount et al. (2009). In addition, when students realized their presumed understanding was incorrect based on the feedback, many were prompted to re-visit and re-explore the simulation model. This is an important step in the inquiry learning process.

Figure 6-1 above also revealed that where an open response was expected, this requirement proved to be the least engaging for students. When investigating in the interview the reasons for this lower engagement, students mentioned one key factor. For example, one student asked for terms to be included in the question that were more scientific: '*You would probably have to use (in the question) a lot more scientific word like particles, atoms, average movement, collisions etc.'* [HTSEM206]. This student suggested that it could have guided him to articulate his thoughts effectively in responding to the answers. Another student further commented: '*I guess that I kind of knew the concept, but I did not really know how to word them. I had some sort of idea in my head but actually articulating them scientifically was what I had difficulty with'* [HTSEM205]. This suggested that even though they 'kind of' knew the concepts, they found it difficult to translate their ideas into suitable scientific language. This finding suggests that there was a need for the module designers to tailor the open response activities by providing scientific terms within the question as a 'hint' to facilitate students' thinking in translating their ideas into words that were scientifically acceptable.

In addition, open responses required students to process and translate their thinking simultaneously while writing, thus increasing the cognitive load. For example, a student responded why he found it difficult to explain and took longer to respond*:*

> I am tweaking in my mind (about the ideas) and you know sometimes it takes me a lot longer to do the things. Obviously, the concepts were not concrete in my mind and so obviously the understanding. Sometimes, you know, just the names of words that you use in scientific language to refer things like the nomenclature, it just takes the time to pick up those words. So, I guess that they are the main reasons as to why it takes me a long time to write out my answers [HTSEM102].

It is proposed that when an open response required students to provide a written explanation of their understanding, this requirement created a higher workload putting stress on working memory. As such, because of the demand to provide a coordinated manipulative and cognitive response, to martial their linguistic resources required to record a written explanation, students appeared to find this type of response excessively demanding leading them to experience this form of response as cognitively stressful.

6.2.2 **The degree of effort students applied to the task**

This study found that students demonstrated high persistence and maintained systematic investigations while engaging with the guided activities. However, the degree of effort students expended in different instructional conditions varied due to differences in students' prior experience. S*ystematic investigation* and student *persistence* have been pursued to understand the degree of student effort in evidence while students were undertaking a task activity (Fredricks et al., 2016; M. T. Wang et al., 2016).

Persistence is defined as learners staying with a task for as long as they can, and in the process facing and overcoming various challenges (Parker, 2003). In this study, student *persistence* refers to the continuation of the exploration process of a simulation model for a prolonged period even when the outcomes of this exploration do not contribute significantly to the learning of a concept. Sometimes, a student wished to explore all features and functionalities of the simulation in spite of having difficulties understanding how these contributed towards learning the concepts. However, this exploration did not necessarily involve a strategic, systematic or organized study of the concepts. Student persistence was coded as 'High' or 'Low' depending on their attempts to explore all the available functionalities of the simulation irrespective of their understanding of the concept. On the other hand, systematic investigation refers to the structured exploration of the concepts, that is, a student attempts to understand a particular concept by exploring it in detail with due regard to the prompts available. This type of exploration engaged a student for a prolonged period in the process of understanding a specific concept which meant that a student might potentially forfeit the opportunity to explore the other available activities pertaining to the simulation. Student behaviour was coded as 'High' when they explored at least two concepts from the simulation activity in a meaningful and structured way; otherwise, it was coded as ‘Low’. To explore and understand student persistence and effort in undertaking the task, the level of engagement with the simulations in both modules has been studied in this section.

Based on the above criteria, the following tables reveal how much effort students invested in systematic investigation and how persistent they were in undertaking the activity.

Table 6-5: Students’ effort invested in systematic investigation and persistent of their effort

Instructional Settings	**Persistence demonstrated (% of students)**	**Systematic investigation demonstrated (% of students)**
Open exploration/ minimally guided (N=21)	Low Persistence = 100% High Persistence = 0%	0 concept = 43% 1 concept= 29% 2 concepts= 29% More than 2 concepts =0%
Moderately guided (N=23)	Low Persistence = 33% High Persistence = 67%	0 concept = 0% 1 concept= 50% 2 concepts= 17% More than 2 concepts =33%
Strongly guided (N=24)	Low Persistence = 25% High Persistence = 75%	0 concept = 0% 1 concept= 0% 2 concepts= 25% More than 2 concepts =75%

The above data revealed that in a self-directed environment, an open, minimally guided activity did not stimulate students to invest high effort in completing the interactive activity. Therefore, low persistence was demonstrated by very few of these students engaging in systematic investigation. In contrast, students showed high persistence when the activities were guided either moderately or strongly. By perusing the above data, it can be seen that students' overall behavioural engagement was higher in guided activities than in the unguided ones. Therefore, the level of guidance proved to be essential in facilitating student engagement with the learning modules.

Besides the instructional guidance, the data revealed that students who had prior online experience demonstrated more persistence and systematic investigatory application in undertaking the activities compared to those who lacked prior online experience.

Table 6-6: Relation between systematic investigation, persistence and prior online experience

Criteria	**Number of student engagement**	**Persistence demonstrated**	**Systematic investigation demonstrated**
Students with prior online Experience (N=20)	28	Low = 6 times (21%) High= 22 times (79%)	0 concept= 0 times 1 concept= 11 times 2 concepts= 11 times More than 2 concepts= 6 times
Students without prior-online experience (N=10)	16	Low = 6 times (38%) High= 10 times (62%)	0 concept= 4 times 1 concept= 5 times 2 concepts= 4 times More than 2 concepts= 3 times

The above table reveals that students with online experience demonstrated higher persistence (79%) compared to students without online experience (62%). In addition, in four instances, students who did not have online experience failed to demonstrate any systematic investigation (0 concepts). In contrast, experienced learners investigated at least one concept during the exploration phase. This suggests that experienced learners were utilizing the learning resources better than the inexperienced learners. This is because the experience with technology or visualizations contributes to success in technology-enhanced inquiry instruction (H. S. Lee et al., 2010; Pallant et al., 2004). Overall, these findings suggest that prior online experience alongside the level of instructional guidance provided, played an important role in engaging students in online learning.

6.2.3 **Students' task accomplishment with MERs**

Students' task accomplishment rate was found to be higher in video activities compared to simulation and open-ended inquiry questions. Their task completion was measured from their interaction with MERs, that is, simulations, videos and open-ended inquiry questions (CgCQs and CnCQs). The following table shows the criteria used to determine students' task completion in this study.

Table 6-7: Relation between persistence, systematic investigation and task completion

MERs	Students' demonstration on persistence and systematic investigation		Task completion assigned
	Persistence	Systematic Investigation	
Simulation activities	Low	0 concept	Incomplete
	Low	1 concept	Incomplete
	Low	2 concepts	Complete
	High	0 concept	Incomplete
	High	1 concept	Complete
	High	2 concepts	Complete
	Criteria for video activity		
Video activities	-Students see the full-length video without skipping any part.		Complete
	-Students did not engage and see the full-length video -Skipping some portion of the video		Incomplete
	Criteria for inquiry questions		
Inquiry questions activities	Three criteria are considered in determining the task as 'complete': -Students correctly addressed the concepts -Students attempted to explain the reasons. It does not necessarily mean a correct explanation was provided. -Students attempted to explain it in molecular terms		Complete

Based on the above criteria, the following table formulates students' task accomplishment rate across various activities.

Table 6-8: Students' task completion rate

Representations	Number of engagement	Task completion rate		Nature of participation that students demonstrated
		Individual	Overall	
Interactive simulation models	Strongly Guided, N=21	76%	57%	Active: required manipulative and cognitive effort to process learning
	Moderately guided, N=23	65%		
	Open/ minimally guided, N=24	29%		
Dynamic videos and animations	pVid1, N= 13	85%	93%	Passive: required cognitive effort to process learning
	hVid1, N= 17	100%		
	hVid2, N= 17	94%		
Symbolic open-ended inquiry questions	CgCQs, N=90	59%	53%	Active: required written input and cognitive effort to process learning
	CnCQs, N=146	47%		

It is noted that, in the simulation activities, the task-completion rate was reduced significantly when they were offered to the students in open or minimally guided situations. This finding supported the previous finding discussed in the above *section 6.2.2* that the students' degree of effort was less in open-ended exploratory tasks. In addition, the data from the table 6-8 reveal that student task-completion rate was much higher for the requirement to view videos compared to student engagement with the simulation activities. This finding was further discussed in relation to students' preferences of using MERs in *section 6.3.1*.

The other notable finding revealed in the above table 6-8 demonstrates the reluctance of students to complete the open-ended questions. In this regard, when students were asked in the interview why they left the activity incomplete, they endeavoured to formulate their thoughts about this behaviour. The following table 6-9 shows a few such responses from their interview in relation to the *CgCQ4.* This question stated, *'*On a cold day when you grab a metal box with your bare hand it feels very cold. When you hold a second box, which is made of plastic it does not feel cold. Explain why the metal box feels colder than the plastic box.'

Table 6-9: The data revealing the reasons behind students' incomplete task

Students' quote from interview	**Reasons for incomplete answer**
I know that metal is a quicker conductor, but yeah, I would actually be struggling with this because I could not think about it. … I know that I experienced it before and I will be kind of getting frustrated, but I still was not able to replay the information. [HTSEM207] (Ref: CgCQ4)	Inability to link back the information to prior knowledge
I am not really sure of the difference between metal and plastic. I don't know if that was really... I get that the hot substances or hot solid is better or will transfer heat faster, but not really sure why metal is colder than plastic or wood. [HTSEM 101] (Ref: CgCQ4)	Surface level understanding; inability to explain the concepts with proper reasoning
I just thought that it holds more heat that's what I was thinking or be more cold than plastic because plastic does not really hold any heat. I did not really know. [HTSEM104] (Ref: CgCQ4)	Misconception about heat transfer; surface level idea about how heat and temperature are related

As demonstrated in the above table, it was a common phenomenon found in this study that when a state of cognitive conflict occurred, students assumed they knew the answer; but when asked to provide an explanation for their responses, they faced challenges in providing sound explanations, leading them to become uncertain and lacking in confidence that they held sound reasons for their answers. This behaviour suggested that their cognitive inability to explain the concepts and the related surface level understanding led them to leave the answer incomplete. In contrast, several students accomplished the tasks successfully. This was because they were able to link their prior knowledge and their ongoing understanding of the activities. Examples of what they said include:

> Both of my previous knowledge and simulation help me to answer it. [HTSEM206]

> I was thinking of the previous simulation that just because of the increase of kinetic energy I just thought that would cause to change shape. [HTSEM104]

> I just using my prior knowledge for the first half. I was not very confident on the paper and metal (question). Like from the previous video I was more aware that the metal removes the heat. [HTSEM105]

Therefore, it is clear that students developed some understanding due to the experiences they had with the modules as their thinking processes were influenced by the activities as well as from their prior knowledge. Once students secured the experience and understandings of the concepts through simulation and video activities, they felt comfortable answering the open-ended inquiry questions.

6.3 Attitudinal engagement

In this study, student attitudinal engagement is defined as students' preferences to work with different modes of representations (e.g., videos, simulations, texts etc.) and their attitude towards following the instructions in different instructional settings.

6.3.1 Students' preference to work with external representations

Earlier sections of this chapter discussed why the video activities attracted higher student engagement and higher task accomplishment over the simulation activities and open-ended inquiry questions. This section further discusses the students' preference and interest to work with the videos over the simulations, because students' preference and interest is a key motivational component of the learning process and influences the quality of learning in multiple ways (M. Yaman et al., 2008). Students showed greater interest and preference for working with videos over the simulation models. Surprisingly, however, most of the students believed that their learning would be most effective through the combined use of videos and simulations. The following figure 6-2 illustrates the students' choices of different representations while learning in the online mode.

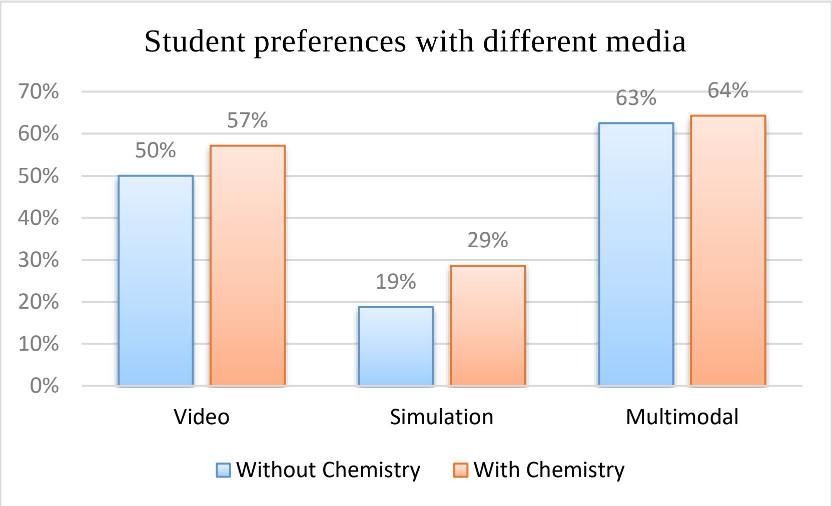


Figure 6-2: Students' preferences for working with the multiple external representations

The above *figure 6-2* evidences that the multimodal environment was more popular compared to the others. In the interview, students disclosed why they wanted to work in a multimodal environment.

Table 6-10: Students' preference to work in a multimodal environment

Student quote	Findings
I think they are all valuable. I think they are kind of add to each other, like with one you just kind of visually observing, the videos.	Videos and simulations complement each other. One provides visual

With the other one, you would kind of having a play and putting into practice and experimenting a little bit more. [HTSEM104]	support while the other gives hands-on experience.
I think I like both. I like the variety of ways to absorb the information. [HTSEM108]	Variety of presentation is key.
I prefer the interaction, actually to get a better idea of how things work. But I liked to watch the video just to get the idea how it worked. I want both, but to me the video is good but it's not giving me everything I need to know. Whereas then I am going to simulation then I could see how actually the thing is working. [HTSEM101]	Multimodal environment gives a more complete understanding of how things work, that is, from different angles.
I like the video most, but at the same time, I think you probably need both of them regardless. So, if I see it in a lot of different ways (both in video and simulation form), I can then have linked it all together a lot easier. They are probably complemented to each other; kind of bring them all together. [PHSEM103]	Videos and simulation complement each other. They help the learner to synthesise the ideas

The above *figure 6-2* also revealed that fewer students were inclined to favour the simulation mode over the video format. Many students were of the view that the simulation only mode in the self-directed environment was insufficient for their overall learning. In the following table, there are several examples of student' opinions about why they preferred videos to simulations.

Table 6-11: Students' preference for videos over the simulations

Phase change module		
Student	**Students' comments on simulation**	**Students' comments on video**
PHSEM202	*I suppose the simulation should open to the browser, not separately. I find usually things are like embedded in the browser. It is a bit confusing. With the interaction of the simulation, I just like more direct sort of approach.*	*I found the video was quite useful because it allows me to contrast the phases of water.*
PHSEM205	*The simulation was pretty hard to understand. Because I had to play around the things myself, and it will better if there somebody actually voicing over or actually explain to you.*	*The video is better than the simulation. It actually showed the difference of the relation between each molecule compares to the simulation. The video taught about the relationship between each molecule.*
PHSEM206	*I did not understand the simulation first. I did not understand what it was and what was I trying to find out first. And I did not realise you can click on the things make thing happens. I did not know that. Usually, I am not a computer person, a book person.*	*I think naturally anyone is happy to see the videos. It explained well, and it helped my understanding of the structures of the water molecules in different phases more clearly. However, I prefer video because the simulaiton was complex.*
PHSEM104	*In this simulation, I don't understand the pressure as much as I do things with the temperature. I do little, but I feel like there was on that too many concepts, you know, happening in the same simulation.*	*I actually learned very well from this video. I don't know why, whether it was... It does show the three different states, it shows molecules, like moving, like real life what would actually be doing. And I think that is why I understood it a bit better.*

	Heat Module	
HTSEM201	*Simulation 2: It did take me a while to like to understand what the simulation is actually doing. Because it did not really have like labels or anything so It's difficult. It's so difficult to find what was the important things here. I think it's just too many activities in one simulation.*	*It is pretty interesting because I like the real-life kind of things. It's pretty entertaining. I can remember exactly like everything that comes from it. So, it was good, like…. And it was good as a break from like, it's just telling you kind of things, so it was good to listen.*
HTSEM202	*This simulation is actually pretty confusing to me because, I can't really like, see the difference between like, how these two particles move, perhaps, like the brighter colour or like a bigger molecule, like to have them differentiate, like which one is cold, and which one is hot. I can't really see that how much particles actually passes through the chamber. It is quite haphazard to me to visualise it.*	*This video is very interesting. This video is the only part I enjoyed in the entire, like the entire experience. It gives me motivation and keeps my concentration. It addresses my misconceptions of the daily life. Because I thought that, the metal was colder than the book. But actually, it is because like book and metal have the same temperature, it is just like how body conducts heat away from the object.*
HTSEM204	*It is not clear about the objective of this simulation. There should be clear instructions of the activities with the simulation.*	*The video was more helpful to me. Because at the end he can explain clearly on the reason behind it. I prefer video over the simulation because it explains the things very short way. From the video, I can learn more because the person in the video discusses more details on the theory and the concepts.*
HTSEM102	*I think the simulation was good for learning, but it required you know to follow around with it, imply with different things. If you have the time to going in actually play around and if you are in that mindset where you want to feel around with the things, but if you just want to go in straight to learn the concepts then they are probably not the best idea, I think.*	*I love the videos because it does not require so much input on your part. But you can just sit back and take it all visually*
HTSEM106	*Yeah, I think it's useful when you ticked the KE shading button. Before then it's not clear that much. The interface is easy to understand.*	*The video was good. I learned that the metal would make the ice melt faster because the coldness from the ice and heat from the metal was travelling through quicker than it was in plastic. And that when you touched something you do not really feel the temperature you are feeling how it's conducting kinetic energy from it to you.*
HTSEM109	*I like it because I am a very visual person when it comes to learning, like a lot of time in the classes when it just the lecture talking and talking, I cannot absorb the information. But in chemistry whenever they have simulations like that really helps to sort of understand what is going on.*	*I prefer probably the video because it's more real life, it's more relatable. I think if you have no background understanding then the video helps because it explains the things.*

The above data revealed that the video format was simpler for the students' receptive understanding of the concepts. Students did not need to actively interact with the video but were nevertheless able to engage visually and cognitively. However, some of the earlier studies revealed that dynamic visualizations (for example video and animations used in this study), especially animations, have some intrinsic problems (Akaygun et al., 2013). Research shows that dynamic visualizations without interactivity may mislead students sometimes and can present too much information simultaneously. Therefore, learners find it difficult to know what is important for their learning (Tversky et al., 2002). Deborah et al. (2013) reported that there are some problems in internalizing the ideas learned from the video animations because students do not have an opportunity to interact with the animations. Students only concentrate on the images shown by the particular animation rather than applying the ideas to their mental models of the chemical system. Tasker et al. (2008) also supported this view by pointing out that students can only transfer their ideas, which they learn from the animation, to familiar situations, but not to a new context because of the lack of these features. That is why this study used the interactive simulations extensively, which required students to engage visually, mentally as well as kinaesthetically.

However, an exception was found in this study which secured higher engagement with the tactile activity compared to other simulation activities. This tactile experience element was embedded in the pSim7 simulation model (figure 6-3). The experience involves a sensation applied to the skin, typically in response to contact or other actions in a virtual world (Burdea, 1996). The simulation model *pSim7* in the *Phase change* module provided students the opportunity to feel the attractions of polar and non-polar molecules and the strength between their bonds. This tactile experience is often described as an active discovery sense that may reduce the cognitive load during learning and thus supports more complex understandings (Jones et al., 2006). The following table shows the summary of the student engagement time on this simulation:

Table 6-12: Student engagement facts in the simulation with built-in tactile perception

Simulation model	**Data extracted from this simulation**	
pSim7: Strength of attractions between polar and non-polar molecules (extracted from MW)	High engagement time set	≥ 2 minutes
	Low engagement time set	≤ 1 minute
	Average engagement time recorded for all students	2 minutes 2 seconds
	Maximum individual engagement time recorded	3 minutes 5 seconds
	Minimum individual engagement time recorded	55 seconds

The data from this simulation activity revealed that the average engagement time for this simulation was above the threshold time set for high engagement. This simulation illustrates the strength of the intermolecular attractions by varying the combinations between polar and polar, polar and non-polar, and non-polar and non-polar molecules. Students chose the molecules of different combinations to feel the attraction and the strength between them. Examples of students' feelings about this simulation are shown below:

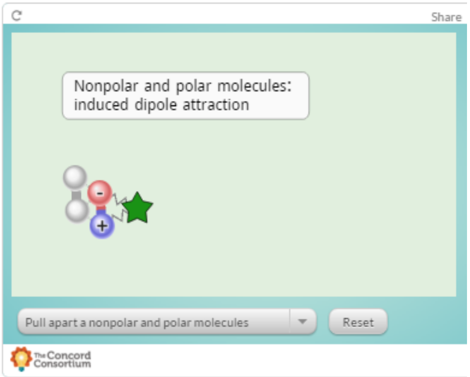


Figure 6-3: Simulation model- strength of intermolecular attractions

Table 6-13: Students' feelings about the tactile experience in a simulation model

Students' quote from interview	Findings
The one at the start I think that one is my favourite (simulation). Because of the pulling the molecules apart from each other, seeing how strong the connections were, that really got me interested at the beginning. [PHSEM101]	Tactile experience providing students the feeling of the strength of the bonds between the molecules; this experience captured student interest in the simulation model.
It helped me to understand, like the difference between the polar non-polar, and how much force you have to give to break them apart. I investigate the amount of pressure to break the bond. Sorry, not the pressure but like the force, it takes to break the bond. [PHSEM103]	Tactile experience and showing the positive and negative charges of the molecules appealed to the students, enabling them to become involved in the activity.
The polar molecules take a lot of effort to break apart because they have negative and positive charges. [PHSEM205]	Tactile experience provides student the experience that a lot of effort was necessary to break apart the polar molecules bond.
Yeah, that one was my favourite. When I have figured it out how it worked, it was really helpful, like you could say that if the things were high in electronegativity like the polar ones like it really strong, whereas non-polar was like so easy to apart. [PHSEM105]	Tactile experience provides student the feeling of the strength of the bonds between the molecules.
Sort of try to play and see the power of the forces (of molecules). I altered the polarity once un-intentionally but then I was doing that intentionally just to try and observe the force to see if it just would wipe around or if it sorts of just repel though. I just curious what happened with it. [PHSEM106]	Tactile experience facilitated further exploration and promoted motivation.
... Showing the strength of those bonds and having little things that you can click and drag as if it makes you feel like you are pulling harder to break the stronger bonds. [PHSEM207]	Tactile experience provides student the feeling of the strength of the bonds between the molecules.

In summary, the tactile experience enabling students to experience the positive and negative charges of the molecules, to feel the attraction and strength of the bonds appealed to the students thus securing their involvement in the activity. The students learned that the charges of the polar molecules caused them to apply more force to break them apart. Due to the appeal of the tactile perception task, many students explored the simulation thoroughly to experience the various combinations. The simulation provides a copybook example of the possibility of self-exploration being successful for learning. During the exploratory process, as the data suggested, some unintentional act triggered some students' motivational curiosity causing them to intentionally investigate the concept. A student expressed his feelings about why a simulation embedded with the tactile experience is a much more powerful tool compared to the video.

> … Say if it was the video of the first simulation where we are trying to drag the two things apart, a video of that one not be effective at all. It would be much better as the simulation than the video because you would not really be able to convey it in the video the same way as the simulation does. If you going to do a video of that you will basically just be repeating what you just said in the text. That does not give you anything extra. [PHSEM105]

In essence, this simulation distinguished itself from the rest of the simulations through the incorporation of a tactile experience element which attracted student interest and promoted them becoming highly engaged with the activity.

6.3.2 Following instructions

In this section, the data suggests that it remained a challenge to deliver a single structured online learning module that could deliver personalized learning experiences for each student. Earlier in this chapter (*section 6.2*), it was pointed out that students were less engaged with the symbolic representations such as open-ended inquiry questions compared to their engagement with the videos and simulations. Furthermore, it was also reported that students engaged more with guided activities compared to open-ended or minimally guided activities. This section further illustrates students' preferences for different types of textual instructional guidance. Though many students preferred instructions, the key finding revealed that many of them found it difficult to follow the instructions in the self-directed environment.

Table 6-14: Student attitudinal approach towards the instruction

Behavioural construct	**Student prefer visual activities (self-attributed) N= 21**	**Student prefer non-visual activities (self-attributed) (N=9)**
Instructional preference (multiple preferences are considered)	<u>Forms of instruction:</u> ▪ 19% of the students preferred initial instructions and then open exploration ▪ 5% of the students' step by step instructions or preference for instructions throughout ▪ 33% of the students preferred instruction on important concepts or preferred specific instruction on what to learn from each activity	<u>Forms of instruction:</u> ▪ 11% of the students preferred initial instructions and then open exploration ▪ 22% of the students preferred step by step instructions throughout ▪ 56% of the students preferred instruction on important concepts or preferred specific instruction on what to learn from each activity

	▪ 14% of the students preferred open exploration (No instruction or minimal instruction): ▪ 33% of the students preferred a combination of instruction and independent learning: <u>Medium of instructions:</u> preferred visual instruction to textual instruction: 5% of the students	▪ 0% of the students preferred open exploration (no instruction or less instruction): ▪ 11% of the students preferred combination of instruction and independent learning: <u>Medium of instructions:</u> preferred voice instructions (Audio instruction): 11% of the students
Difficulties in following instructions	24% of the students	44% of the students

The data shows that most of the students who preferred visual activities sought some form of instructions within the activities. Only 14% students favoured an open exploration format. Of those with a non-visual preference, no student from this category favoured open explorations; rather, all of them wanted instructions to varying degrees. A crucial aspect of the findings was that 24% students with a visual preference faced difficulties in following the instructions. In contrast, in the case of students with a non-visual preference, considerably more, that is, 44% of students experienced difficulties in following the instructions. These findings suggest that in total a large number of students faced difficulties in following the instructions in the online setting. Many students expressed their views on this issue in the interview. Below is a conversation between the researcher and a student in this regard:

Researcher: That is why an instruction was given- "keep heating past 600K until both substances boiled" (pSim2). If you pass the heat over 600K, you will see that the polar molecules will start separating from each other.
PHSEM104: Oh! Do they? OK. I don't think that they would go in that high (in temperature). I read the instruction, but I just saw when the temperature got to the top, there was a line, that is the 600K, and then there had a little section above it, so I filled the section above it. I did not think you could just keep going.

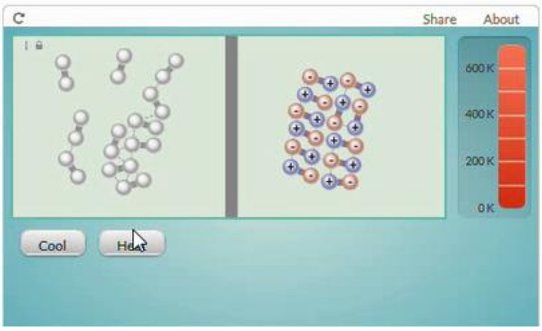


Figure 6-4: Simulation model- Polar and non-polar liquid (pSim2)

Researcher: There was another instruction given on how to remove the cover (pSim6). Did you follow the instructions?
PHSEM104: Genuinely not. Because I could not remove the cover. Because I was clicking the cover button, not remove the cover. I don't know.

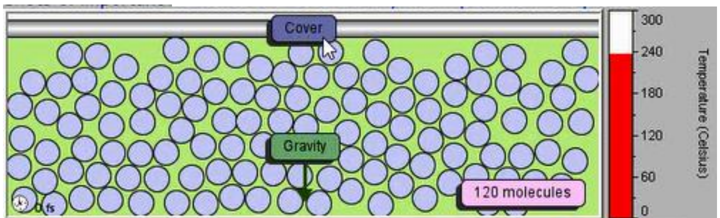


Figure 6-5: Simulation model- Evaporation model (pSim6)

Researcher: Do you think you found it difficult to follow the instructions?
PHSEM104: Yeah, I always look at something first and then read the instructions. But if I feel I can know what I am doing, I don't read the instructions, which is really bad in everything. And I do need to change it. Yeah, I should read the instructions first.

The above student held a visual preference for learning and so preferred an open exploration. However, he demonstrated difficulty in following the instructions and therefore executing the simulation functions. First, the student assumed that the temperature would not go beyond the visible line in the temperature bar (pSim2) and so inferred that the temperature would not reach very high, for example, to go beyond the 600k. This inference impacted upon the student's thinking, that is, in undervaluing the importance of the pertinent instruction, he failed to experience the behaviour of the molecules' extreme hot condition. This behaviour interfered with the student's meaningful engagement with the task. More generally, it can be noted that this kind of behaviour could lead students to experience a decrease in their intrinsic motivation to learn the material.

Second, in the *pSim6* simulation model, the student showed a tendency to skip the instructions because of his presumption that he knew what he was required to investigate. This case highlights an issue that, when students considered that the instructions were of less value in their exploratory process, it resulted in an unstructured investigation being undertaken, and, as a result, led to less engagement and low learning outcomes. It is because of this student tendency to be overconfident in their ability to learn independently in a learning environment that this disposition caused them to resist acknowledging the importance of the instructions to provide assistance. In relation to another similar situation (*hSim3* simulation model), a student commented in the interview about this particular behaviour.

> The instructions said to heat or cool. But I just heated it all the way to see like to get it overflow. Because that was my intention. I did not think to cool it. I just think of heating. I don't think it will just come back to its original volume when cooled. [HTSEM103]

This student faced difficulties in following the instruction even after reading the instructions. By analysing the student's reflection in the above comment, one can observe that the instructions did not register as sufficiently important to override the fixed position held by the student. Thus, in this situation where there was an inner contradiction experienced between what he read (instruction) and what he believed was correct (established erroneous knowledge), his preconceived view prevailed. That is, he was entrenched in his understanding of what would happen once the system cooled down. The nature of this mindset needs to be recognized as an important issue in the self-directed learning, that is, that some students may not follow the instruction even after reading the instructions. It is a challenge, in the absence of a teacher, to ensure that students read the instructions and follow them to attain the intended learning outcomes.

In designing the instructions, it thus seems imperative that textual features or audio narrated instructions be employed to communicate the necessity to adhere exactly to particular instructions. As 11% of students (table 6-14) perceived the necessity of voice instruction, this mode might assist students to visualize the infinitesimal, but fundamental relationships in the simulations. A recent study demonstrated that the screencast, containing voice instruction from an expert, facilitated students in gaining a more complete understanding of the particle-level behaviour; this tool, that is, the verbal narration of the screencast assisted in drawing students' attention to details and improved their understanding of the processes (Herrington et al., 2017). Herrington et al. (2017) also suggest that students might be able to identify the pattern readily in the simulation as these supports effectively reduce the cognitive load for the students.

Other students facing the difficulties of following the instructions did so because of a misunderstanding stemming from the complex terms used in the activity. Textual information, because of the prevalent lexical density, requires careful reading to achieve understanding, a requirement which some students found too demanding. The student below, for example, could not process all the information without reading the text repeatedly in one of the activities.

> Few times, I have found that, like, the text is too much to read. It needs a couple of more times to read because, it is the first time I read it, and not really think about it. And it would be a whole lot of really complex terms and, so I have to read it again and really thinking and focus on it. It is sort of dense topic in this subject matter; it is not like easy reading. [PHSEM105]

To understand further the issue that this student faced, the actual text and representation of the content is shown below:

The strength of the interactions between dipoles can be classified into two groups: weak and strong interactions.

1. Weak interactions are created through the interaction of instantaneous dipoles (dipoles that exist only transiently). These interactions are called London dispersion attractions. We describe these types of molecules as being non-polar.
2. Stronger interactions are created through the interaction of permanent dipoles. These interactions are called dipole-dipole attractions and occur in molecules such as water or sugars (e.g. glucose). We describe these types of molecules as being polar.
   Now think about the following and find the answers by changing the viewing mode in the simulation.

- How do the attractions (green lines) differ between the non-polar and the polar molecules?
- How do the colours, representing the charges of the dipoles, change?
- What does this mean for the instantaneous dipole?

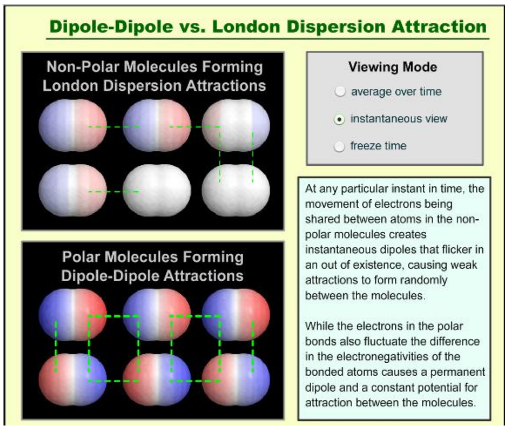


Figure 6-6: Simulation model- dipole-dipole vs London dispersion attraction

This student was interacting with the *pSim8* simulation model in the *Phase change* module where the *Dipole-dipole vs London Dispersion* attraction was discussed. The student thought that the new concept and complex vocabulary made it difficult for him to understand the content without repeated readings of the text. One possible reason that the student faced the issue of dealing with the lexical density of the text was a lack of prior knowledge about the topic. It was revealed in the interview that indeed he lacked prior chemistry education. The above data thus suggest that understanding and acting upon the texts were partly contingent upon whether or not students had prior experience of the subject matter.

In brief, the findings suggest that students required some level of explicit instruction as a condition for their completing the activities in the self-directed learning environment. However, many students faced difficulties following the instructions adequately due to their assumptions and incorrect inferences, lack of prior experience, complex terminology, and the lexical density of the textual information. Besides, several students had the tendency to be overconfident in their ability to learn independently which potentially interfered with their ability to following the instructions faithfully. These findings again indicate the need for individualised learning accommodations in the endeavour to improve students' engagement and learning.

6.4 Cognitive engagement

The findings in this section are discussed under two subthemes: a) students' cognitive effort in the simulation activities, and b) students' cognitive effort in response to the inquiry questions.

6.4.1 Student cognitive effort in simulation activities

Because simulations are the central learning component in the learning modules, students' cognitive engagement with the simulations potentially defines their success in an online environment. Similar to previous findings, the data revealed that prior experience and guided activities facilitated students' cognitive engagement.

To investigate how the students were cognitively engaged, the *Snapshot* feature, embedded in three simulations of *Heat* module, is discussed here. This feature is a kind of formative tool, which allowed students to capture instant images of important moments during their interaction; they were then asked to explain their understanding of why they thought the captured moment was important. When students clicked the snapshot button, a text field with the captured image appeared in which students needed to explain their understanding (e.g., figure 6-7). Students' responses were adjudicated as

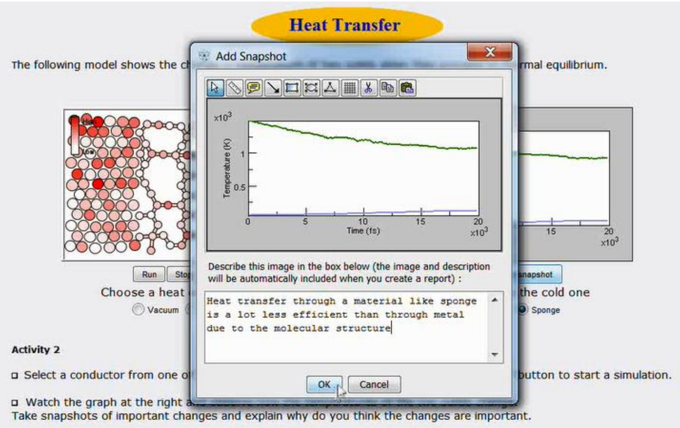


Figure 6-7: Student taking snapshot and writing response

‘high’ in cognitive effort when they explained the phenomena demonstrating causality, that is, why something was happening or what reasons they could cite to explain the specific behaviour of the molecules. If students only described ‘what’ they were observing or experiencing, then their efforts were considered as being at the surface level. To better understand this component, the following table breakdown each individual’s performance on this task across three simulation models of the *Heat* module.

Table 6-15: Students’ approach to explaining the concepts in the snapshot

Students [N = 17]	**hSim1** Strongly guided		**hSim2** Moderately guided		**hSim3** Minimally guided		**Rate of high cognitive engagement**
	What	Why	What	Why	What	Why	
Students with Chemistry background							
HTSEM201 (Exp.)	√	×	√	×	√	√	Considering instructional guidance: Guided activity = 47% Unguided/ minimally guided = 29% Considering online experience: With online experience = 29% Without online experience = 10%
HTSEM202	√	×	√	×	√	√	
HTSEM203 (Exp.)	√	√	√	√	√	√	
HTSEM204	√	√	√	×	√	×	
HTSEM205 (Exp.)	√	×	√	√	√	×	
HTSEM206 (Exp.)	√	×	√	√	√	×	
HTSEM207 (Exp.)	√	√	√	√	√	×	
Students without Chemistry Background							
HTSEM101(Exp.)	√	√	√	√	√	√	
HTSEM102	×	×	√	√	√	×	
HTSEM103	√	√	√	√	√	×	
HTSEM104	×	×	√	×	×	×	
HTSEM105	×	×	√	×	√	×	
HTSEM106 (Exp.)	√	√	√	√	√	√	
HTSEM107 (Exp.)	√	×	√	×	×	×	
HTSEM108 (Exp.)	√	×	√	√	√	×	
HTSEM109 (Exp.)	√	√	√	×	√	×	
HTSEM110	√	×	√	×	√	×	
Exp. = Student with prior online experience							

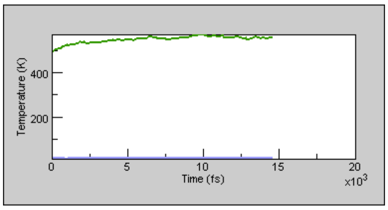
It is evident, as illustrated above, that most of the students failed to explain why it happened or the reasons behind that phenomenon. In all three simulations, similar patterns were observed. It is clear that the majority of the students failed to engage deeply at a cognitive level irrespective of their chemistry background. Predominantly, the data revealed that students showed less cognitive effort in an unguided environment compared to the effort exhibited in response to the guided settings. This is probably due to the insufficient instructions being available about ‘when’ and ‘how’ to take the snapshots of the important moments in the simulation activity. This lack of instructional guidance caused students to take the surface level approach and therefore they were removed from engaging deeply.

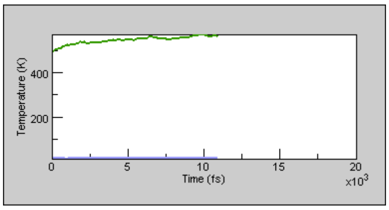
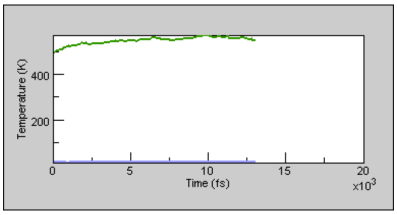
Similar findings were observed in the *Phase change* module where a student reported that the open exploration mode was difficult for him to understand: '*The simulation was pretty hard to understand. Because I had to play around the things myself, and it will better if there somebody actually voicing over or actually explain to you'* [PHSEM205]. However, when the simulation was provided under guided settings, students were able to change parameters correctly and understood the concepts through the assistance of the instructional guidance. A student commented how the instructions helped him to understand a concept: '*With increasing the pressure and decreasing volume, it would have actually explained Boyle's law and the increasing temperature as well. Because they are bouncing off the walls a lot more and causing a lot more pressure' [PHSEM103].*

Alongside the instructional guidance, the other reason that influenced students' cognitive engagement was the open-ended nature of the snapshot feature which demanded both manipulative and cognitive effort to demonstrate their understanding. It is to be noted that this finding also supported the previous findings discussed in the *section 6.2.1*, reconfirming that whenever students needed to explain a concept where an open response was required, that is, without any prompts being provided, they became less engaged and less inclined to commit to an answer.

In addition, this study also found that students who did not have prior experience and were novices in using technology could not utilize the snapshot features properly in the online environment. This finding supports the recent findings by K. Meyer (2014) who stated that those who are new to the online environment may be especially prone to a lack of engagement. As this study revealed, simulation features and buttons for various functions proved to be confusing for these students; they frequently failed to implement them properly even after clear instructions had been given. The following are a few examples extracted from the students' interviews reporting how they responded to the snapshot feature alongside their original written responses:

Table 6-16: Students' opinions about the snapshot feature and their written explanation

Students' quote from interview	**Students' original written response in the snapshot**	**Researcher's Reflection**
I am struggling with the discussion after I have taken the snapshots. And I don't know what to write. I thought that I have to capture the initial moments and find out the variables inside and so that I can run the simulation. In fact, I don't like the snapshot. [HTSEM204]	 *Vacuum is not a good heat conductor since the lines do not meet (Ref. hSim2).*	The student responded to 'what' was happening by mentioning what he observed; student demonstrated a surface level approach to explain that a vacuum is not a good conductor. This student didn't have online experience.

The snapshots just take the picture and its nothing to say. Like, ya, you can see the colours of the different energies of different sizes, but that does not tell you all that much. [HTSEM206, online experience]	 *With the vacuum, since there are no particles in contact, then no heat is transferred, and the temperatures remain constant (Ref. hSim2).*	The student thought the snapshot was not a useful feature as it represented only a portion of the information. However, the student responded to 'why' by explaining that there were no particles in the vacuum to transfer the heat. This student had prior online experience.
Instead of just playing around with the staff like that actually, I have to be critical and explaining it myself, which I think, is good. I think it is really good. [HTSEM205, online experience]	 *Heat is not transferred through a vacuum as there are no particles to carry the kinetic energy between the two materials (Ref. hSim2).*	This student found the snapshot feature was useful for learning. The student responded to 'why' by explaining that there were no particles in the vacuum to carry the kinetic energy and therefore no heat transfer took place. This student had prior online experience.

The above comments suggest that the first student lacked the ability to process his thinking synchronously with his interactions with the activity requirements, that is, once he took the snapshots he struggled with the requirement to discuss the key concepts in the given text field. This behaviour was found to be similar to that demonstrated by other novice students. Technology tools, such as the snapshot feature in this study, often require the enlisting of considerable cognitive resources as students need to learn to how to use, skim, grasp, and manipulate data (Kim et al., 2011). Students became disoriented in the online learning context due to the large number of resources they encountered; in particular, they collectively produced an extraneous cognitive load (Sweller et al., 1998), that is, learning the functions and how to use the snapshot feature. The students also showed less cognitive engagement when they lacked adequate prior knowledge and experience (Kim et al., 2011). In such cases, students are inherently limited in their ability to think critically (Land et al., 1997) and thus tend to focus on the surface level of a problem rather than engaging in meaningful inquiry and higher cognitive engagement (Kim et al., 2007). This finding suggests that students with a lack of online experience need to be exposed to preparatory interventions prior to their participation in the online modules. This deficit could possibly be remediated by constructing individualized learning modules for such students to induct them into some fundamental concepts prior to their being exposed to a mainstream module.

In contrast, students who had prior online experience, demonstrated better cognitive engagement as they found the snapshot feature was supportive of their study. They found it to be a supportive learning tool because it assisted them in becoming critical learners. This finding is reinforced by evidence that prior experience with online learning encourages greater student engagement (Fisher, 2010). Therefore, in brief, the findings suggest that playing with the simulations alongside being provided the opportunity of explaining the important facts in the snapshots provoked experienced learners to be more critical and more reflective in ensuring that in-depth learning occurred.

6.4.2 Student cognitive effort in response to inquiry questions

This section investigates the level of cognitive effort students demonstrated in responding to the inquiry questions, in particular, the cognitive conflict questions (CgCQs) and concept check questions (CnCQs). The findings arising from the inquiry questions are further discussed in the next chapter in relation to the students' learning approaches. The purpose of these questions was to stimulate students' deep thinking about their conceptual experiences. The following table illustrates students' cognitive engagement with the inquiry questions.

Table 6-17: students' cognitive engagement with the inquiry questions

Types of questions	**Measuring criteria**	**Rate of High' cognitive engagement**
CgCQs [6 CgCQs, number of engagement, N= 90]	*High cognitive engagement* = Students think and explain concepts at molecular level *Low cognitive engagement*= Students only identify concepts but failed to relate and explain at molecular level	59%
CnCQs [10 CnCQs, number of engagement, N=146]	*High cognitive engagement* = Identify, apply the concepts to explain and solve the given problems *Low cognitive engagement* = Only identify the concepts related to the problems	47%

The data revealed that students' level of cognitive effort in response to these questions was mediocre. Though many students demonstrated higher order cognition in their responses to the questions, there was a significant number of students who demonstrated only low level cognitive engagement. To understand more deeply how the students thought and engaged cognitively, the following two students' quotations obtained during the interviews were analysed. Crucially, the students demonstrated higher cognitive engagement by establishing a relationship between the strength of intermolecular forces and the boiling point.

Table 6-18: Student demonstrating higher order cognition and understanding

Students' quote	***Students level of understanding***
You would need a lower temperature to break apart non-polar bonds compare to polar molecules. It means the non-polar molecular have a lower boiling point. [PHSEM103] *The high boiling point shows it polar. The polar ions… they stick together and so that is a sign of a strong intermolecular force. If you tested it… the high boiling point actually tells you how strong the forces are. [PHSEM104]*	Both the students accurately related the concepts of higher or lower boiling points of a substance to the strength of intermolecular bonds of that substance. This is a higher order understanding which was not taught in the activities.

The above two exemplars are good examples of where higher order cognition was displayed by the students. Other perspectives revealed in the interview also confirmed the prevalence of students' engaging in higher order thinking. For example, one student expressed the notion of thinking about the perspective of the person who actually wrote the questions. This student tried to think what answer the person who wrote this question wanted from the student. He commented: "Actually, I am thinking about how the person who wrote it wants it to be phrased. Maybe that also fits into kind of understanding, which is not fully formed yet in my mind." [PHSEM207]

The student believed that this kind of thinking assisted him to understand the concepts, which were not yet fully developed in his mind. The perspective of putting himself in the mind of the questioner indicates that the student had the capability to think about a problem reflectively. This element of metacognitive and reflective thinking appears to be a vital disposition in the self-directed learning environment. If the learning module were designed in a way that motivated students to ponder the teacher's perspective, then higher cognitive engagement is more likely to be revealed in the learning situation. Briefly, the ability of a student to realize what he/she knows or does not know in relation to a concept is significant as the student is demonstrating a metacognitive awareness that could lead to refining his/her understanding. Thus, such a student is not working "blindly" but with his/her mind fully engaged.

Another notable finding was pertaining to the wording of the concept check questions, which might often influence students in processing their understanding. For example, the *CnCQ1* stated: 'Explain why water is often liquid, but oxygen (O_2) is always a gas at room temperature'. It was found that the word 'room temperature' elicited a higher level of attention to a student. Example:

> I think I got a little bit look down by the 'room temperature' thing. I was thinking a little bit too much about 'room temperature' and how that would affect the molecules instead of just thinking about the bonds. And the fact that there is a like the water, dipole bonds, like the polar bonds, whereas the oxygen would be non-polar bond. So, I was excited, I think a little bit too much, on that (room temperature) than the actual question. [PHSEM103] (Ref: CnCQ1)

So, there was a potential risk to mislead the student's thinking in an unproductive way even though the quality of thinking was pitched at a deep level. Therefore, it is important to carefully select the words for formulating a question; otherwise, instead of scaffolding students' thinking in a specific direction, it instead diverts them causing them to engage in fruitless higher-order cognition. In contrast to the above findings, it was also found that many students showed low cognitive engagement across the learning modules. The following table summarized some of the causes that led to lower order cognition during the activities:

Table 6-19: Causes that led to lower order cognition during the activities

Cause	Effect	Result
Open/ minimal guided activity	Unstructured exploration and low behavioural engagement	Low cognitive engagement
Use of multiple simulations, as they demand active participation	High workload (and potential overload)	
Complex simulation interface with rich information	Students were overloaded with information	
Lack of prior experience in online learning	Difficulty in coping with the environment and utilising the materials and therefore less meaningful exploration	
Student tendency to be overconfident in their ability to learn independently	Difficulty in following the instructions and therefore less meaningful exploration	
Misunderstanding stemming from the complex terms used in the activity	Difficulty in following the instructions and therefore less meaningful exploration	
Open-ended inquiry questions	high workload (and potential overload)	

In brief, a lack of instructions, deficits in prior experience, the open-ended nature of the simulations, and so forth hindered many students in activating their higher order cognition.

6.5 Conclusion

Student abilities to engage and learn while working in the online self-directed learning environment vary markedly; such differences, based on many factors, become particularly apparent in this context for learning in the absence of teacher supervision. Hence, the absence of opportunities to receive immediate personal feedback, reduces the opportunities for students to control and interact with their learning environment, thus raising the likelihood that their level of engagement will be diminished during learning activities (Krause et al., 2008; Tuckman, 2007). Importantly, this study endeavours to determine the factors that influenced student engagement in this self-directed online environment.

The first key finding is that instructional guidance positively affected students' engagement with the learning modules. Students showed high persistence and systematic investigation in guided settings thus demonstrating higher engagement compared to engagement levels in unguided activities. However, not all students reaped the benefits from the instructional guidance. This study revealed that students who self-identified as visual learners did better in following the instructions compared to students who self-identified as non-visual learners. In fact, many students with a non-visual preference displayed an inability to follow the instructions successfully in the self-directed environment. This was because of their lack of prior experience, the need to comprehend complex terminology, and the lexical density of the textual information used in the activity adding to the comprehending load. In addition, due to the tendency to be overconfident in their ability to learn independently, many demonstrated a tendency to pre-empt the task requirements ignoring the instructions in large part.

Second, in the context of the self-directed online environment, this study represents the first in depth exploration of students' perceptions about which MERs they find most supportive. The findings suggested that not all MERs were equally effective in engaging students. Demands of the MERs activities affected students' engagement level. All the simulation models and inquiry questions placed a higher cognitive workload on students as well as demanding physical responses compared to the videos, animations or synchronous feedback. However, when the students were provided with guidance, they demonstrated a higher task completion rate in the simulations. On the other hand, the low level of active commitment required in viewing the videos and providing feedback in the self-directed environment elicited high engagement. This was reflected in the students' task accomplishment as well. These findings suggest that both the interactive and dynamic visual activities could facilitate higher student engagement when suitable scaffolding is provided to ensure students do not experience cognitive overload leading to a reduction in their engagement levels. Furthermore, this chapter represents the in-depth exploration of students' perceptions about which MERs they find most supportive in the self-directed online environment, an understanding minimally reported in the literature.

In the feedback sections, where the misconceptions were corrected, and clarification of students' answers was provided, these features elicited high engagement. One key similarity between the video and the required feedback is that both appeared to encourage students to become passive learners in the sense that they were not expected to act expressively, that is, to manipulate material (express) in response to the input. Another important finding is that, when provided with a simple interface, the tactile perceptions in the simulation models facilitated higher student engagement. Students demonstrated high engagement with the given simulation irrespective of the instructional settings and prior experience of the students.

In brief, as explained in previous chapter findings, the quality of instructional guidance and prior online experience was key in engaging students with the online learning environment. When the MERs were scaffolded and meshed cohesively with the instructional guidance, the students demonstrated high behavioural, cognitive and attitudinal engagement with the activities.

Chapter 7

Students' Approaches to Learning

7.1 Introduction

This chapter presents the findings pertaining to the students' approaches to learning in online settings. These findings emerged from the data stemming from student interactions with the learning modules. The diversity in learning approaches is a result of the complexity of individual learner differences based on their prior experience, learning preferences, and so forth. However, four key themes capturing the raft of influences impacting on student approaches to learning became apparent. These are: a) prior online experience, b) subject knowledge, c) instructional settings, and d) students' representational competence for understanding the abstract science concepts.

7.2 Students' approaches to learning

In this study, approaches to learning refer to how students interact with the learning modules and what strategies they adopted for learning the concepts. Some research studies, categorizing student approaches to learning have described them in terms of the level of engagement, commitment to a task, and the strategies employed, that is, at a surface or deep level (Biggs, 1987a; Entwistle et al., 1979; Marton et al., 1984). In this study, these terms have been adopted to characterize students' approaches to learning that emerged during their interaction with the learning modules. The following table reveals the themes relating to the approaches to learning that students exhibited during their interaction with the module activities.

Table 7-1: Approaches to learning emerging from students' interaction

Approaches to learning	Behaviour demonstrated	Evidence from observations	Source of data
Deep	D1. Understanding the simulation model comprehensively	Time on task, persistence, systematic investigation, use of hints	Observation, video record, and interview
	D2. Showing persistence and high interaction	Time on task, persistence	
	D3. Discovering simulation functions and integrating them with prior understanding	Systematic investigation, following instructions, responding to question prompts	
	D4. Experimenting with new ideas	Systematic investigation, exploring beyond the instruction, searching for new concepts and relations between the concepts	
Surface	S1. Understanding the basic functions of the simulation models	Time on task, following instructions, exploring the common simulation parameters	
	S2. Minimal exploration without showing meaningful understanding of the concepts	Exploring parameters of simulation, low persistence, no systematic investigation	

These behaviours were observed and recorded across different simulation activities in the learning modules. In addition to the above findings, the data further revealed that students' interactions and their approaches to learning were largely influenced by their prior online experiences and subject knowledge. As part of the interview protocol, students were asked whether they had any prior online experience and subject knowledge; their responses were categorised accordingly with the table below illustrating these relationships.

Table 7-2: Relation between online experience, subject knowledge and learning approaches

Learning Approaches	**Behaviour demonstrated**	**Prior online experience and subject knowledge (Self-reported)**			
		Students with Prior online experience (Number of engagement, N= 43)	Students Without online experience (Number of engagement, N= 25)	Students with Chemistry (Number of engagement, N= 32)	Students without chemistry (Number of engagement, N= 36)
		Frequency of demonstration			
Deep	D1. Understanding the simulation model comprehensively	25 (58%)	7 (28%)	17 (53%)	15 (42%)
	D2. Showing persistence and high interaction	22 (51%)	5 (20%)	13 (41%)	14 (39%)
	D3. Discovering simulation functions and integrating them with prior understanding	21 (49%)	8 (32%)	16 (50%)	13 (36%)
	D4. Experimenting with new ideas	16 (37%)	6 (24%)	10 (31%)	12 (33%)
Surface	S1. Approach to understanding the basic functions only	17 (40%)	18 (72%)	14 (44%)	21 (58%)
	S2. Minimal exploration without showing meaningful understanding	14 (33%)	14 (56%)	9 (28%)	19 (53%)

The following sections discuss the above findings in detail.

7.2.1 **Prior online experience**

The data from the above table 7-2 revealed that prior online experience impacted upon students' approaches to learning positively. To understand how prior online experience influenced students' approaches to learning, three examples of student behaviour *(see table 7-3)* are analysed here. The simulation model *hSim1* (fig 7-1) represents a closed system of two chambers separated by a door. One chamber contains hot (reddish) gas molecules and the other one contains cold gas (light green) molecules. When students clicked on the 'Run' button, the simulation started and the door between the two chambers was removed. Thereafter, the molecules between the two chambers started flowing to each other. This simulation helped students to see how hot and cold gas molecules were mixing between the two chambers. A student could add or remove heat from both the chambers to see how the molecules behaved with the change of temperature. The following table 7-3 shows some examples of students' behaviour.

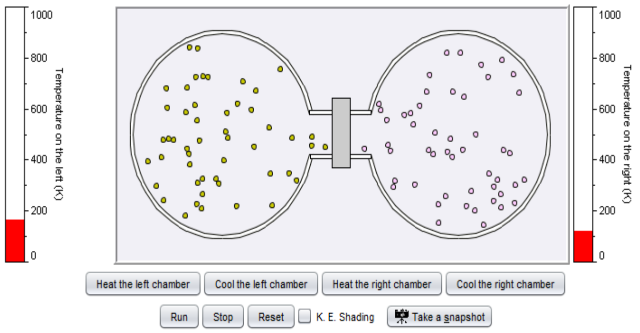


Figure 7-1: Heat transfer between two closed chambers

Table 7-3: Students' learning approaches and behaviour observed in the simulation activity

Student	Observation of student behaviour	Remark
HTSEM207: A student with prior online experience	Student successfully runs the simulation on the first attempt by clicking on the 'Run' button. D1: After running the simulation, student observed the simulation for a while to understand how the simulation is functioning. Then he started to follow the instructions. This helped the student to understand the simulation environment and the associated concepts. D2: Student frequently revisited the simulation model and demonstrated systematic investigation of some concepts. D3: During the interaction, the student was able to use the 'Run' and 'Reset' buttons frequently to understand the simulation model. The student was able to use successfully the 'Take a Snapshot' feature too. Once student clicked on the 'Take a Snapshot' button which stops the simulation, and the captured image appeared with the text box. Then the student explained his understanding in the given text box.	Deep approaches to learning were demonstrated: D1, D2, and D3. Prior experience helped the student to follow the instructions and facilitated exploration and understanding of the simulation model.

HTSEM102: Without prior online learning experience, but had other simulation experiences	Student found difficulties running the simulation at the beginning. <u>D2</u>: Student clicked on the 'heat the left chamber' several times to initiate the simulation. He tried dragging the simulation where the door between the two chambers is placed. Finally, the student found the run button to run the simulation. Thereafter, the student showed persistence in exploring the simulation model and had a good time as a whole. <u>S1</u>: During the interaction the student clicked on different buttons and functions of the simulation but could not really engage with them for a sufficient time to explore these for a comprehensive understanding of the particular concepts related to those functions.	Both deep and surface approaches to learning were demonstrated: D2 and S1. The student had initial difficulties but with time, he overcame it.
HTSEM204: Without prior online and simulation experience	Student found it difficult to run the simulation. <u>S1:</u> Initially student was clicking here and there and began to become familiar with the simulation environment. It took nearly 5 minutes for him to understand the simulation environment and only then was the student able to run the simulation successfully. <u>S2:</u> Student clicked on the *'Take a snapshot'* button several times, as he thought it would initiate changes in the variables (confirmed in the interview) and run the simulation. He then read the instructions but did not follow them properly and clicked on the different sections of the simulation incorrectly. He tried to explore the top menu bar of the simulation window too. But the student frequently gave up exploring and understanding any of the simulation features.	Students took longer than usual, but basically demonstrated surface approaches to learning such as S1 and S2 criteria. Student found it very difficult to interact and explore the simulation. He even found difficulties following the instructions.

The above data suggested that, given the lack of prior online experience, students without prior experience faced twofold challenges while interacting with the environment. For example, HTSEM204 had to learn two things during the activity. First, the focus was to learn the simulation skills pertinent to the simulation environment, such as learning how to run the simulation, the functions of simulation and then shifting the focus to exploring the concepts. As the student's attention and learning focus was divided, he spent more time learning how to manipulate the simulation than exploring it for the concepts. This eventually resulted in his experiencing cognitive difficulty in processing the information he learned to facilitate the immediate exploration of the simulation. When new information is provided to inexperienced learners, they usually experience a heavy cognitive load (Kalyuga et al., 1999; Kirschner, 2002). HTSEM204, as an example of this phenomenon, was unable to probe for understanding during the interactive process. He focused on learning the basic functions of the simulation and thus was precluded from gaining deep insights into the topics. Therefore, he showed less ability in grappling with the problem, adopting a surface approach to engage cognitively in solving the science challenges. This process exemplifies the challenge of such inexperienced students to engage deeply in the self-directed environment.

A possible way to facilitate students' deep approaches to learning in the self-directed online mode is to provide them more specific support in orienting them to the task in the form of instructional guidance. Instructional techniques and guidance could reduce working memory load (Van Gog et al., 2005). Del Valle et al. (2009) reported that the learners who did not have a learning orientation to tasks spent the least amount of time online, and during this time demonstrated a surface approach to the task. Therefore, in the self-directed environment, a pre-learning session or learning orientation might be a viable solution to facilitate deep approaches to learning for students who appear shackled by a paucity of prior experiences in working in online contexts.

Conversely, HTSEM207 and HTSEM102 with prior online experience demonstrated more efficient, skilled performances in exploring and understanding the simulations. This is because learning tasks with a high degree of interactivity encourage students with high prior knowledge by giving them more options to explore and opportunities to use higher order thinking skills by manipulating simulation parameters (Park et al., 2009; Tuovinen et al., 1999). This finding implies that interactive simulations enhance learning for students with prior experience because they usually have sufficiently developed schemas and adequate working memory capacities (Kalyuga, 2005; Kalyuga et al., 2003; Park et al., 2009). The findings, therefore, suggest that prior online experience is a key ability that affects student approaches to learning positively in the self-directed online environment.

Besides the students' backgrounds, the findings confirmed that students' ongoing experience and ability to learn and cope quickly with the environment also influenced their approaches to learning. It helped them to gain familiarisation with the MERs and their functions, which impacted positively on their learning approaches. For example, several students acknowledged that familiarisation with the activities in the earlier stage of modules facilitated their success during the later stages. In particular, the earlier exploration and experience with the guided simulation activities assisted students to better understand the complex and rich simulation activities. The background knowledge and experience derived from the previous activities made it easier for students when they encountered new simulation models. Some examples of students learning from experiences are the following:

> The simulation with the instructions helped at the start to get the general idea of the things. So, when I got to that one (the other less guided simulation), I was able to have things in my mind that I already knew. So, by the time I got to that, the background information had helped me. [PHSEM101]

> I know from the previous simulation that heat transfer is affected by few factors. Like surface area, air movement and there are some other factors which helped me. [HTSEM104]

> The previous activities helped me to understand the problems. [HTSEM105]

The above comments revealed the usefulness of the previous activities in facilitating the students in becoming familiar with the format and design of the activities, so when they reached the more challenging activities, students were prepared. Developing familiarisation with the activities in the online environment contributed to the development of the students' confidence (Fesakis et al., 2009; Kear et al., 2012). This familiarisation process provided guidance and served the students in enabling them to pace the learning process (Milligan, 1998). This was also found to be important in regard to their potential to engage with the online activity as suggested in another study (Phelan, 2012). To summarise, students used their ongoing experiences by gaining familiarisation with the sophisticated simulation models to engage and explore confidently in the later activities of the learning module. This eventually promoted student's deep approaches to learning in the self-directed environment.

7.2.2 Prior subject knowledge

Some researchers have proposed that approaches to learning may be influenced by a learner's background, prior experience, instructional settings and learning environment (Biggs, 1987a; Duarte, 2007; Entwistle et al., 1982). The data in the above table 7-3 support these research findings by revealing that students with prior subject knowledge tended to demonstrate deeper approaches to learning.

In this section, students' written responses to various concept check questions (CnCQs) have been analysed to specifically understand how subject knowledge influences students' approaches to learning and their subsequent learning outcomes. Moreover, approaches to learning reap consequences in the process of influencing learning outcomes (Yang et al., 2010). Indeed, many studies have found positive relationships between students' approaches and learning outcomes (Ellis et al., 2006; M. H. Lee et al., 2008; P. S. Tsai et al., 2017). The following table illustrates the key themes that emerged from their written responses casting light on students' learning outcomes.

Table 7-4: Learning outcomes, level of understanding and prior subject knowledge

Level of understanding	**Learning outcomes demonstrated**	**Prior Subject Knowledge (Self-attributed)**	
		With Chemistry (Number of responses, N= 70)	Without chemistry (Number of responses, N= 76)
		percentage of demonstration	
Surface	Recalling the information	3 (4%)	11 (15%)
	Identifying facts and information	8 (11%)	12 (16%)
	Describing facts and components of argument	21 (30%)	26 (34%)
	Total frequency of demonstration at surface level	***45%***	***65%***
Deep	Integrating and linking present knowledge with prior experience	15 (22%)	4 (5%)
	Understanding and reasoning	16 (23%)	14 (18%)
	Drawing and justifying conclusion	7 (10%)	9 (12%)
	Total frequency of demonstration at deep level	***55%***	***35%***

The above table 7-4 reveals that 65% of students' responses emanating from the 'without prior knowledge group' fall under the category of surface level learning, far higher than the 45% demonstrated by the 'prior subject knowledge group'. Conversely, 55% students from the prior subject knowledge group demonstrated deep learning compared to 35% of the students without the prior subject knowledge. This suggests that, in the self-directed online learning environment, students' prior subject knowledge appears to influence their approaches to learning. It is no surprise that students with more knowledge of science could explain their understandings in a more lucid way than those without this background. The following two examples revealed how the learners with prior subject knowledge responded to the questions and how their background knowledge helped them in this regard.

Table 7-5: Examples: Students' responses influenced by prior subject knowledge

Students original written response	**Students' quote from the interview**	**Reflection**
Since a vacuum has no particles in it, it stops conduction by allowing the particles to collide, so if there are no particles to collide with, heat won't be transferred, and the temperature will remain constant. [HTSEM206] (Ref: CnCQ9)	*I have known these concepts from year 11 and 12 that helped me to answer these. I have to apply the knowledge from this simulation and previous studies to some extent. Like, I have never heard that example before, so I have to apply it in a new situation.* [HTSEM206]	HTSEM206 studied chemistry in high school, and thus he found it easy to answer the concept check questions. The student was able to apply his prior chemistry understanding together with the present knowledge on offer to answer the question.
When having a hot shower, water molecules at a high temperature are being sprayed out of the shower head at a significant velocity. With this kinetic energy, alongside the heat of water, a significant number of water molecules are being released from the hot water as vapour. As such, these molecules would fly around the bathroom and end up making contact with the mirror, where they would come into contact with the metal and cool back into a liquid as more water molecules make contact with it, causing the fog. [PHSEM207]	*It is not a chemical reaction, but obviously like when you touch a piece of metal, you feel cold, means a lot heat transfer is going around, So I am not sure if endothermically applies to just reaction or to any transfer?* [PHSEM207]	PHSEM207 had benefitted from a chemistry background; therefore, he was able to address the given problem by drawing on prior chemistry knowledge. He tried to explain the phenomenon with the endothermic process at first, which was not taught in this Phase change module. However, due to uncertainty about its "rightness", he removed it from his final explanation.

The above data revealed that the students were able to demonstrate deep level learning processes which include reasoning, understanding, and integration of prior knowledge. For example, PHSEM207 tried to relate the given problem to his prior chemistry knowledge of the endothermic process to explain what was occurring. However, the phenomenon (endothermic) he was explaining was not a chemical reaction; when anyone touches a piece of metal, it feels cold, which means heat transfer is occurring. This approach to solving the problem clearly indicated that his higher order thinking ability was in play. On the contrary, students without a chemistry background did not have this "well" of educational experience to draw upon in explaining the problems. For example, a student commented in this regard- '*All the concepts are new to me. I haven't learnt this apart from today. I hadn't even thought about oxygen just being oxygen, you know, like O_2. Yeah, and I didn't even think of them as both being positive or the both negative'* [PHSEM104]. (Ref: CnCQ1). Another student reported- '*Obviously, the concepts were not concrete in my mind and so obviously the understanding'* [HTSEM102].

Therefore, a lack of chemistry knowledge may have contributed to limited understanding and reasoning ability, which many students demonstrated in giving their explanations. These students consequently demonstrated surface level learning compared to their more experienced peers. Below are some examples of students' responses that reveal surface level learning.

Table 7-6: Examples: student responses influenced by the lack of prior subject knowledge

CnCQs	**Key Concepts in this problem**	**Examples of students' written responses**	**Student demonstration**	**Researcher's Reflection**
CnCQ1. Explain why water is often liquid, but oxygen (O_2) is always a gas at room temperature.	-Role of hydrogen bonding in water molecules -Non-polar oxygen molecules and weak intermolecular forces	*Due to the bonds created by the hydrogen atoms.* [PHSEM102] *There are no hydrogens to form bonds in oxygen gas.* [PHSEM105]	Recalling the information	Students failed to explain the problem by using the key concepts. Students simply stated the presence/ absence of H-bond without any explanation.
CnCQ5. Explore the simulation of water molecules to explain why ice floats in molecular terms.	-Objects with greater density sink in lower density fluids. -In ice, the molecules hydrogen bond together and the bonding is directed to particular shapes (hexagonal) that leave empty gaps so the solid takes up more space than the liquid.	- *Ice floats because the water molecules are bonded together in a very rigid structure. The liquid molecules are also bonded but have more speed and break and form bonds as they move about.* [PHSEM103]	Identify facts and information	The student mentioned only the nature of bonding of ice and liquid water. Student could not link the concept that structure has an important role in the ice floating in water.
CnCQ8. In a popular lecture demonstration, a	- Metal conducts heat the faster. It would quickly take	*The paper would burn on the metal half of the rod, not*	Describing facts and components of argument	The student explained the concept incorrectly.

rod that is half wood and half metal is wrapped tightly with a sheet of paper. If held over a flame, the paper on one half of the rod burns while the paper on the other half is unaffected. Which half of the rod has the burnt paper? Explain with reasoning.	away the heat from the flame without affecting the paper around it. - Wood is a bad conductor, it could not take the heat away from the flame faster, so the paper around the wood would be affected and burn.	*the wooden half. This is because metal would conduct heat to the paper more efficiently than that of the wood, so it would burn first.* [HTSEM106]		The student knew that metal is a good conductor but failed to apply that knowledge in this given problem.
CnCQ10. The iron plate pictured here has a hole cut in its centre. What will happen to the hole when the plate is heated? Explain in molecular terms with reasoning.	- The iron atoms vibrate more due to the increase in heat energy. Each atom takes up more space. Consequently, on average each atom is further apart from its neighbours. The atoms that line the edge of the inner hole effectively make a circle of atoms. If the distance between them increases, then the circle becomes bigger. In effect, the hole increases in size.	*When the plate is heated, the circumference of the hole will decrease because the solid object undergoes thermal expansion. In other words, the particles in the solid object gain more kinetic energy (from the heat source) and more collisions occur. In order to reach equilibrium, they naturally want to space out more and the object swells. If the volume of the object increases, the volume of the hole will decrease.* [HTSEM102]	Describing facts and components of argument	The student knew the concept of thermal expansion but failed to rationalise what happens to the inner circumference of the hole in terms of thermal expansion. Student misinterpreted it and said that when the plate is heated, the inner circumference of the hole will decrease because the solid object undergoes thermal expansion.

The above data evidence a common phenomenon that students knew the basic concepts but failed to use those concepts to provide rational arguments when explaining the given problems. On the other hand, there were examples where students were able to transact the concepts with sound reasoning and understanding to explain the same problems. The following table shows such examples of students' responses for the same CnCQs.

Table 7-7: Student responses to concept check questions

CnCQs	Key Concepts in this problem	Examples of students' written responses	Student demonstration	Reflection
CnCQ1. Explain why water is often liquid, but oxygen (O_2) is always a gas at room temperature.	-Role of hydrogen bonding in water molecules -Nonpolar oxygen molecules and weak intermolecular forces	*Water is a liquid because its ability to hydrogen bond so effectively with other water molecules means that there are likely to be vast numbers of very tightly packed H_2O molecules (forming liquid). However, oxygen is a gas at room temperature because it doesn't have this unique hydrogen bonding ability, thus is a gas.* [PHSEM106]	Understanding and reasoning	The student showed sound understanding and reasoning about the presence of H-bond between two water molecules that helped to form a liquid. However, the absence of H-bond is not the correct reason for oxygen molecules being a gas.
CnCQ5. Explore the simulation of water molecules to explain why ice floats in molecular terms.	-Objects with greater density sink in lower density fluids. -In ice, the molecules hydrogen bond together and the bonding is directed to particular shapes (hexagonal) that leave empty gaps so the solid takes up more space than the liquid.	*Ice in molecular form is not densely packed as water is, the molecules are in hexagonal shape with space between the bonds making it less dense than water and therefore lighter, so it floats.* [PHSEM104]	-Drawing, justifying, and conclusion	Student demonstrated excellent understanding and reasoning. Student identified that the ice has a hexagonal shape and there is space between the bonds and so it is lighter than the water
CnCQ8. In a popular lecture demonstration, a rod that is half wood and half metal is wrapped tightly with a sheet of paper. If held over a flame, the paper on one half of the rod burns while the paper on the other half is unaffected.	- Metal conducts heat the faster. It would quickly take away the heat from the flame without affecting the paper around it. - Wood is a bad conductor, it	*The wood, because it is unable to transfer/conduct the heat as well as the metal* [HTSEM109] *The paper on the wood half of the rod will burn. However, the paper on the metal half of the wood will not*	-Integrating and linking present knowledge with prior experience	The student was able to transform the ideas to justify their understanding in this given problem. Students also used their prior

Which half of the rod has the burnt paper? Explain with reasoning.	could not take the heat away from the flame faster, so the paper around the wood would be affected and burn.	*burn because the metal is a better heat conductor and will remove the heat from the paper through contact more efficiently than wood will.* [HTSEM105]		understanding that metal is a better conductor of heat than the wood.

The above data reveal the deep level of learning where students demonstrated their understanding and reasoning powers in explaining the problems. Many researchers have noted the reconstructive conception of learning at the upper levels, which they suggest reflects a constructivist view of learning in contrast to ones where learning is applied superficially, for example, memorization at the surface level (Burnett et al., 2003; Purdie et al., 2002). Moreover, the constructivist view of learning suggests that learning is concerned with understanding and meaning which might be demonstrated by relating or connecting new concepts to prior knowledge (Biggs, 1994). As such, students who demonstrate deep learning attain superior learning outcomes (M. H. Lee et al., 2008; Purdie et al., 2002;).

In brief, the data in this study supports the position that in the self-directed online learning environments, the extent of prior subject knowledge may affect students' approaches to learning. Researchers have indicated that students with low prior knowledge are less likely to benefit from interactive simulations because they may not have developed adequate schemas to guide them through the process of understanding concepts (Moreno et al., 2005). Conversely, a student with prior knowledge in particular relevant disciplines, notably chemistry and physics, is more likely to have interpreted the simulations and the concepts effectively, reducing the overall complexity of the activities (Podolefsky, Adams, et al., 2010). It appears that prior knowledge of a discipline creates for the student a state of readiness for learning new concepts. Established schemas appear to be implicated in providing a springboard for this to occur. This finding potentially contributes to understanding the connection between approaches to learning and self-regulated learning.

7.2.3 **Instructional settings**

The data also revealed that guided activities could better facilitate students in demonstrating deep approaches to learning compared to open/minimal guided settings, a finding similar to those revealed in the previous chapters. The following table represents the students' approaches to learning in various simulation models in different instructional settings.

Table 7-8: Students' learning approaches in different instructional settings

Learning Approaches	Criteria	Strong guidance N= 21	Moderate Guidance N= 23	Open/minimal guidance N= 24
			Frequency	
Deep	D1. Approach to understand the simulation models comprehensively	14 (67%)	12 (52%)	6 (25%)
	D2. Showing persistence and high interaction	12 (57%)	10 (43%)	5 (21%)
	D3. Discover simulation functions and integrate them with prior understanding	10 (48%)	11 (48%)	8 (33%)
	D4. Experimenting new ideas	6 (29%)	7 (30%)	9 (38%)
Surface	S1. Approach to understand the basic functions only	7 (33%)	11 (48%)	18 (75%)
	S2. Minimal exploration without showing meaningful learning	6 (29%)	7 (30%)	15 (63%)

The notable findings that stand out in the above table are that in 'experimenting new ideas', open/minimal guided activity promoted a higher frequency of deep approaches to learning. It was probable that the nature of open exploration facilitated students in experimenting with new ideas. To support this viewpoint, below is an example of a student's behaviour in an open-ended and minimally guided environment.

Observed student behaviour: Student *PHSEM207* interacted with the *pSim1* (PhET simulation) simulation model in the open-ended setting. There was a barometer in the simulation model to measure the pressure level of the system that indicated how the temperature affects the pressure in real time. It was observed that the student used the lid of the container to change the volumes, which caused the changes in phases of the selected substance (e.g., H_2O molecules), temperature and pressure. The student used these parameters intuitively during the investigation of the simulation to observe the changes of pressure and temperature in real time, which assisted him to explore the concept of Boyle's law further. This student also used the injector to inject additional molecules and notice the temperature and pressure changes in the live barometer. The student understood the relationship among the temperature, pressure, and molecules in a closed system which helped him to understand Boyle's law.

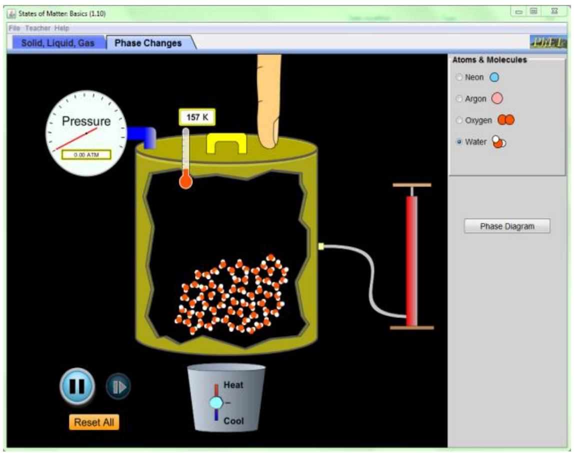


Figure 7-2: pSim1 model from Phase change module

Student comment: I think simulation itself can guide. The whole idea is kind of like, just a make your own way through this sort of things and especially play around with all the concepts. Manipulate all these things and answer the questions, do what you want... kind of get yourself involved and learn in deep level sometimes. [PHSEM207]

Remark: The student's comment indicated that the affordances of the simulation model guided him towards productive exploration without explicit guidance. When the question was asked why the temperature was constant while the pressure was changing at a particular point on the phase diagram, the student further explained:

> The temperature is constant because the system is isolated and there is no further input of heat energy. Pressure is constantly changing because the number of evaporated molecules is constantly changing, and therefore changing the number of interactions outside of the liquid area. [PHSEM207]

The student came to an understanding of this concept on his own through the appropriate use of the features and parameters of the simulation.

This is a good example of a student experimenting with new ideas in an open-ended simulation model. However, as observed, for many other students, open exploration or exploration with minimal guidance did not work effectively. It was found that, in open and minimally guided activities, initially students explored the basic functions to become acquainted with the simulation models but lacked the ability to process their thinking in synchrony to understand the concepts behind those functions. Consequently, they failed to explore meaningfully and eventually produced unsystematic minimal efforts that did not contribute to their adopting deep learning approaches. Incorporating more explicit instruction into the "fabric" of the modules could influence such student approaches to learning thus contributing to their developing conceptual understanding (Sinapuelas et al., 2015). Furthermore, Moreno et al. (2000) stated that students who receive explanations and learning instructions in a personal and supportive manner, develop a deep approach to learning, and display an ability to solve problems. In line with this viewpoint, Garrison (2011) also argued that there are instances where direct instruction is required to achieve deep and meaningful learning for the students. In brief, this study confirmed that students adopted deep approaches to learning when more explicit and detailed instructions were provided in the self-directed environment.

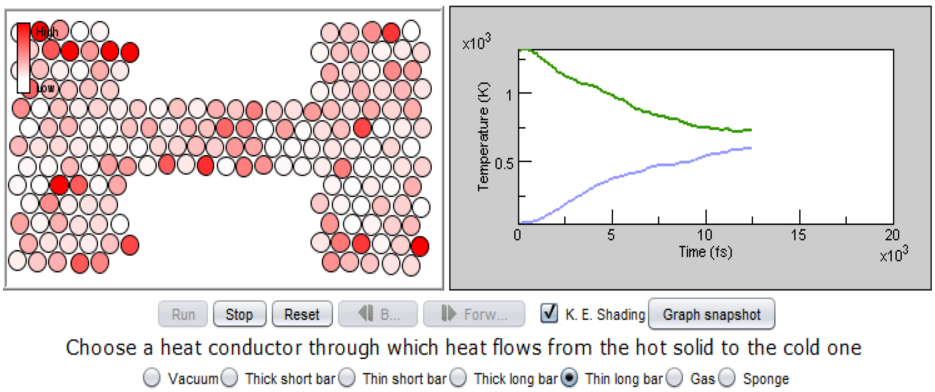
7.2.4 Students' representational competence

In this study, students' representational competence, specifically understanding and translating sub-micro level phenomena, contributed to their developing mental models of the abstract science concepts and influencing their approaches to learning. In science education, it is challenging to obtain a consistent and genuine understanding of students' mental representations (Coll et al., 2005; Greca et al., 2000). However, by referring to their external behaviour manifested within a specific context, educators can gain insights into their cognitive constructs (Gobert et al., 2000; Ibrahim et al., 2013). For example, in this study, students' approaches to interacting with the online learning modules and their subsequent behaviour were considered as a form of external manifestation that could infer the kinds of mental representations that they held. The following table depicts some of the themes that emerged from the data while students were interacting with the learning modules.

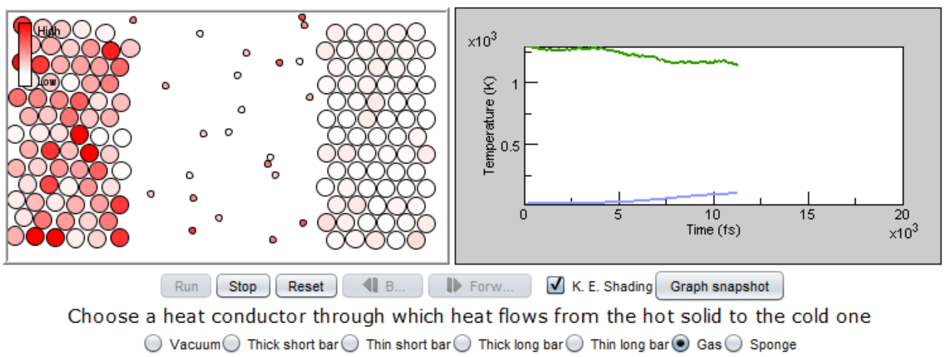
Table 7-9: Examples of students' representational competence emerged in this study

Representational Competence	Representations studied
Ability to visualize the unobservable and unreported properties	hSim2
Ability to translate the representations into meaningful understanding	pSim1, pSim5, hSim1, hSim2 and hSim3
Ability to differentiate between the representation and actual object	pSim1, pVid1

Ability to visualize the unobservable properties: The ability to visualise unobservable and unreported properties of the objects at the sub-micro level helped students to understand the abstract science concepts. For example, in the *hSim2* simulation model (figure 7-3), the surface area of the conductors affects the heat transfer process. From the given simulation, students observed a 2D interface in which the coordinated surface area of the molecules was difficult to grasp.



Two objects are connected through a thin long bar



Two objects are connected through tiny gas particles

Figure 7-3: Students' representational competence demonstrated in simulation model, hSim2

Moreover, students were seeing part of the conductors at the sub-micro level, not the complete structure of the conductors. Therefore, to understand the role of surface area in the heat transfer process, students needed to interpret the picture of a 3D coordinated system of the conductors. In addition, they were required to correctly construct the intermolecular structure of the given conductors such as vacuum, thick short bar, thin long bar, gas, sponge and the relative size of the molecules. The data revealed that several students were able to create a mental model of the heat transfer process through different conductors by pointing out the role of the conductors' surface area. A few notable comments are shown below in this regard:

Table 7-10: Students representational competence to depict the conductor's surface area

Student quote from interview	Representational skills
I found the thicker the bar the faster the heat could transfer. But if it is only a short bar like a small amount of molecules to transfer heat, it took a lot longer. Because of its thickness (thick short bar), the surface area is one of the reasons as to why the heat transfer is faster. [HTSEM104] *It would kind of just showed me the different path with thick and thin objects and how fast the heat conducts with regards to surface area. [HTSEM207]* *In the gas, because of tiny particles moving back and forth, heat could not really move quickly over the tiny surface area of the molecules.* [HTSEM106]	Students understood that a small number of molecules have less surface area and a large number of molecules have big surface areas. Similarly, gas particles are tiny and therefore less surface area is available for the particles to collide and transfer the heat. Students were able to translate the idea of the surface area in understanding the overall heat transfer process.

The above data revealed that students' visuospatial ability such as the perception of unobservable properties, as in relation to the 3D coordinated surface area of the conductors, contributed to their developing a mental model and facilitated deep approaches to learning. Students were able to translate and relate the idea of why the solid conductors have faster heat transfer ratios than gases and sponges. As the surface area is smaller in the gases and sponges, the contact ratio between the molecules is low and therefore the heat transfer process was lower.

Translating the representations into meaningful understanding: Science simulations can depict imperceptible changes in matter (e.g. colour changes, making and breaking the bonds, feeling the intermolecular force and attractions) at the sub-micro or molecular level. Students are required to recognize and accommodate these changes to understand the concepts.

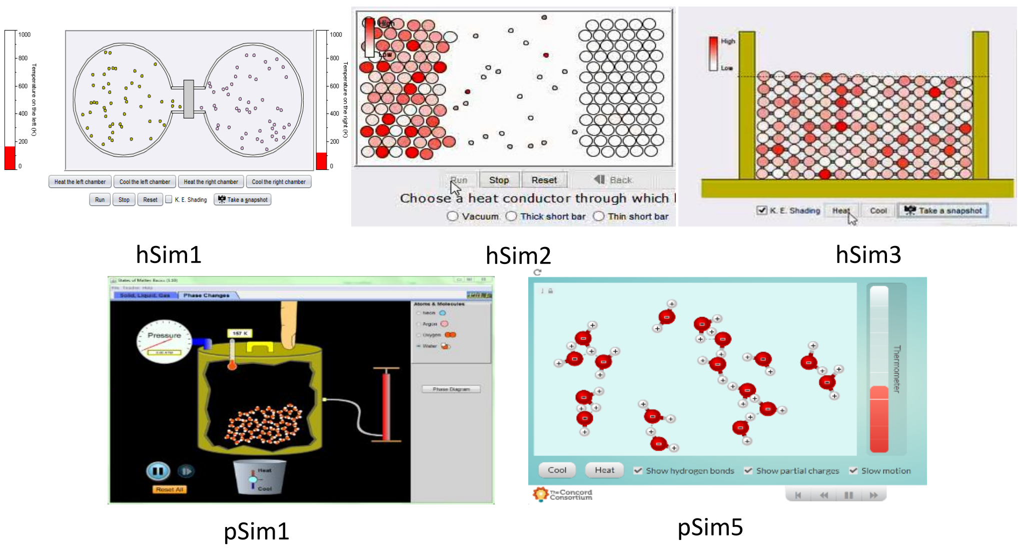


Figure 7-4: Key simulations used in *Heat* and *Phase change* module

However, students' inability to relate and translate this information within and across representations was found to be the main inhibitor to the comprehension of the learning concepts (Ibrahim et al., 2013).

This study found that students who were capable of sensing and discriminating the changes of the molecules at a sub-micro level were able to visualize and understand the molecular properties and the connections between them. For example, in *hSim1, hSim2 and hSim3* simulation models (figure 7-4), one important phenomenon was to make sense of the meaning of the colour of the molecules. Students needed to understand that the redness of the molecules represents the thermal energy or kinetic energy of the individual atoms. Once they understood how and why the molecules were becoming red, they were able to translate this behaviour to understand the process of heat transfer. This study found that several students noticed this change and understood it successfully. Other students required more specific instructions because, either they did not notice this change or could not relate this change to their extant understandings.

Similarly, in pSim1 and *pSim5* from the *Phase change* module, students were expected to gain comprehensive knowledge about the intermolecular structure of water and oxygen molecules. Specifically, in pSim1, they were supposed to understand the concept of the H-bond. Here, one particular example is studied to clarify how students exhibited their learning approaches using their representational competence.

Table 7-11: Student representational competence and learning approaches

Question	Written responses of PHSEM106	Written responses of PHSEM101
CnCQ1. Explain why water is often liquid, but oxygen (O2) is always a gas at room temperature.	Water is a liquid because its ability to hydrogen bond so effectively with other water molecules means that there are likely to be vast numbers of very tightly packed H_2O molecules (forming liquid). However, oxygen is non-polar and it doesn't have this unique hydrogen bonding ability, thus is a gas at room temperature.	Water is often a liquid because of its specific boiling point. Oxygen is always a gas at room temperature because it does not take much heat for it to become a gas. Oxygen is also electro-negative. By hydrogen and oxygen combining, it changes the charge of water.

The above data shows that PHSEM106 addresses two key concepts; the presence of H-bonding in water but not in oxygen and the non-polar nature of oxygen molecules. As observed during the activity, PHSEM106 was able to visualise and understand the attraction between the two water molecules and formation of the H-bonds in *pSim5*. PHSEM106 reported:

> The simulation is good to visualise. Because you see the little lines in there as soon as the molecules got close to each other. You can visualise that. The hydrogens are being attracted to the oxygens molecules to form the hydrogen bond. [PHSEM106]

PHSEM106 was able to notice the creation of little lines between the hydrogen and oxygen atoms between two water molecules and perceived it as the formation of hydrogen bonding. The collision and interaction between two water molecules within the simulation model enabled him to develop a mental model of how the hydrogen bond forms. In addition, the student understood from pSim1 that oxygen is a non-polar molecule and strong bonds between the molecules could not occur. Through such representational competence and abstract reasoning, PHSEM106 built his understanding and thus he was able to address the key ideas of the problem. This is a good example of a student employing a deep approach to learning.

On the other hand, PHSEM101 failed to address the key ideas indicating a lack of understanding of the concept. PHSEM101 did not really engage with the simulation for an adequate time. When he was asked why he failed to address the concepts, PHSEM101 replied:

> I think it's because often I see things a lot of time and I assume that I understand it. So, when I saw that simulation is very similar to a lot that I have seen before, I thought I understood it and I did not really need to look at the simulations carefully. Obviously, that simulation went in more depth... [PHSEM101]

It is evident that the student focussed on the concept superficially due to his overconfidence which precluded him from gaining deep insights into the topics. A deficit of representational competence in understanding the phenomena of the concepts results in a cognitive failure to develop a sound understanding of the concepts. This student was unable to draw upon representational competence and probe for understanding during the interactive process. The other data in this study demonstrated that some students were able to exhibit well-developed representational competence enabling them to notice the sub-micro level behaviour; from observing this successful behaviour one can infer the quality of their understanding of the concepts. Following are a few examples:

Table 7-12: Student representational competence facilitated understanding of the concepts

Student quote from interview	**Concepts student learnt**	**Remark**
I did not know before that the electrons are moving so much and that is why they constantly making those different bonds... I also did not know specifically about the polarity… how the bonds clash between the negative and positive forces and how they just stay, like so stable. [PHSEM103] (Ref, pSim5)	The student was able to understand the role of polarity in making the stable bonds between the atoms.	Student able to visualise the moving electrons and how they contribute to the development of the bonds. The student was aware that this representation was very new and contributing to his knowledge.
I see the clash and the distinctions between two edges of the molecules on the way that was spinning and	Intermolecular structure of liquid water and the	The student held some assumptions about liquid water molecules behaviour. Then, his simulation model

specifically colliding (to each other). I got a sense of the behaviour of molecular interactions, which I suspected, but I never actually seen before in my studies. [PHSEM207] (Ref. pSim1)	intermolecular attractions	helped him to experience the dynamic behaviour of the liquid water molecules such as their collisions, spinning, and interactions. He was able to contrast and compare this experience with his prior assumptions.
I saw these atoms bouncing around. Well this particular example that says it between hot and cold in a room, so in my mind I can see if you open the door, I can see the molecules in a hot area moving a lot faster that all transfer through to the cold air. [HTSEM101] (Ref. hSim1)	Heat transfer process and the thermal equilibrium. Student also identified the molecular kinetic energy	Student's ability to see the bouncing atoms in hot temperature helped him to understand the relationship between temperature and kinetic energy and heat transfer process. This understanding facilitated the student to make a real-world analogy where the hot air passes to the cold rooms.

One important notion that emerged from the above data is that all three students noticed and were attracted by the movements of the atoms and molecules. This movement of the atoms and molecules contributed to their understanding of the abstract concepts of heat transfer, kinetic energy, making bonds, and so forth. It has been reported that when the animations effectively direct students' attention to their key features, it helps them to avoid overloading working memory, and promotes meaningful understanding of the concepts that could effectively integrate with their prior knowledge (Tasker et al., 2006).

Ability to differentiate between the representations and actual object: Student ability to differentiate between the representations and the actual object affects their learning approaches too. The objects in the real world are made of trillions of molecules. But, the representations, specifically the simulation models and videos are comprised of a small sample of the model objects made up of "countable" molecules (see figure 7-4). To understand this representational competence, two examples are studied below-

Table 7-13: Student representational competence

Students' quote from interview	**Representational competence**	**Remark**
This simulation is just with the handful of atoms which is so so tiny compared to actual water. I guess I was thinking that most of it were more or less the same just on a larger scale. [PHSEM105] *It shows molecules moving like real life... and the number ... you know usually you just see a couple of molecules whether it should like so so many.* [PHSEM104]	Students made the real world analogy here with the small scale of water volume presented at sub-micro level in the simulation model	Students were able to differentiate between the simulation model and the real world. With just a handful of atoms in the simulation model, the student understood that it partially represents the actual world.

Students here interpreted the sub-micro level behaviour of the substances by making an analogy to the real world. Interpretation of representations and making an analogy to the real world require learners to understand the relation between the representation and the domain that it represents (Ainsworth, 2006). Interpretation of the representations and translating representations involve thinking about the phenomenon at three different levels of representation — macroscopic, symbolic and sub-microscopic. Many novice learners are unable to create a mental link between the three levels of thinking simultaneously. This may result in rote learning to acquire fragments of unrelated information (Sim et al., 2014). In contrast, once students are able to make the analogical representations of real world situations, it helps students to construct conceptual mental models (Ibrahim et al., 2013). Therefore, a clear perception of the difference between the representations and the actual objects is a necessary representational competence in the process of learning to exercise deep learning approaches.

In brief, the power of the representation resides in its quality of enabling students to visualise unobservable events; a simulation does, however, demand higher order thinking. This is particularly true in the case of science with two dimensions of understanding being involved: the macroscopic and the sub-microscopic. Students with this ability to understand perceptually exhibit deep approaches to learning. However, not all students have demonstrated these skills successfully in the self-directed environment. Indeed, it could be an important topic for further research to find out the factors that can facilitate students' perceptual understanding of science phenomena in the self-directed environment considering the standard use of multimodal scaffolding in online learning modules in the process.

7.3 Conclusion

This chapter discussed students learning approaches in relation to the students' prior online experience, subject knowledge, and their representational competence in the self-directed online environment. Similar to previous findings discussed in the last two chapters, students' prior knowledge and experience appeared to be an important factor that affected students' learning approaches. In addition, it was found that strong instructional guidance facilitated students' deep approaches to learning compared to the provision of moderate and minimal guidance. Further, students who were able to demonstrate representational competence and were able to develop a mental model of the abstract science phenomena were able to demonstrate deep approaches to learning. However, in the process of learning conceptualisation, a greater number of students exhibited surface learning compared to those who were able to engage at a deep level learning required for success in the self-directed environment.

The findings of this study reveal that prior online experience played a vital role in student approaches to learning. Learning in the self-directed online settings differs from the traditional environment where direct interpersonal support mediates learning. In the online context, students obtain support through online resources and different scaffolding strategies embedded within the learning modules. As such, students who can best utilize these resources, materials and scaffolding tools potentially benefit most from this environment. In this current study, students' ability to manage and learn in the environment independently facilitated their learning more deeply in comparison with their peers who lacked these skills.

Chapter 8
Discussion and Conclusion

8.1 Overview of this chapter

In this chapter, the key findings that emerged from the study, pertaining to the three research questions are presented in the context of the broader research fields to which they relate. First, the role of scaffolding design in inquiry-based, online and self-directed learning environment (RQ1) is discussed. Second, how this scaffolding design influenced students' engagement (RQ2) is explored. Third, the students' approaches to learning in the self-directed online environment (RQ3) are explained. Finally, the key findings, followed by a discussion of the results' implications, the limitations of the study, recommendations and future research directions are presented.

8.2 Introduction

The rationale for online learning is, primarily, to minimize traditional study constraints in terms of access, time, place and pace to provide more flexible and personalized learning environments (Paiva et al., 2016). Despite great promise that the results for students are overwhelmingly beneficial, success in an online learning environment relies on an individual student's ability to actively engage with and self-regulate the learning process (C. H. Wang et al., 2013). Therefore, the ability to design environments that engage and are sympathetic to students' self-regulating their own learning is a crucial factor underpinning successful online learning (Barnard et al., 2009). In addition, there is a growing demand for studies that demonstrate suitable scaffolding frameworks and are bolstered by convincing evidence that their implementation promotes students' self-regulation skills. However, the lack of pedagogical guidance to support students' self-regulation and the integration of sophisticated technologies into the instructional design remain key challenges in developing online learning environments.

To address this challenge in this research study, a scaffolding framework was introduced based on an adaptation of the well-documented and commonly implemented predict, observe and explain (POE) pedagogical strategy by adding a fourth step evaluate (E) in the expectation that this extra process would enhance the core strategy. The addition of this extra step to the POE strategy, forming the POEE strategy, prompts students to evaluate or reflect upon their thinking undertaken during the three previous stages. This POEE scaffolding framework has been employed here in the context of a self-directed online learning environment in which both teacher and peer support are absent. The design and development of this scaffolding strategy were described in chapter 4 and are based on individual and social constructivist theories and related methodological understandings described in chapter 3. Three research questions guide this study. These are:

RQ1. What role can scaffolding play to facilitate student learning in online learning modules?

RQ2. What factors influence student engagement in their exploration of the learning modules?

RQ3. What learning approaches do students apply in understanding the science concepts?

The key findings that emerged from analysis of the data in this study suggest that the POEE scaffolding strategy enables the creation of a constructivist environment through provision of four essential criteria - a) elicitation of prior knowledge; b) creation of cognitive dissonance in a student's mind; c) opportunity to apply the new knowledge; and d) opportunity for reflection and clarification (Baviskar et al., 2009). These four conditions of a constructivist learning environment are realised in the actions of the students in response to the POEE scaffolding strategy implemented as part of the instructional design in this study.

8.3 Summary of findings

In response to the investigation of these three research questions, this study elicited three major findings to be considered as required elements for the effective implementation of self-directed online learning.

Table 8-1: Three key findings resulting from this study

Research focus	Scaffolding (RQ1)	Engagement (RQ2)	Learning approaches (RQ3)
Key findings	This study demonstrated and conceptualized POEE as a multimodal scaffolding strategy that can provide constructivist learning environment	The results of this study confirm the importance of intrinsic motivation for student engagement in an online environment. The POEE strategy, instructional guidance, and the nature of self-directed inquiry learning essentially provided this intrinsic motivation.	Students' prior experience, representational competence and the ability to develop their mental models of abstract science concepts, combined with the support of instructional guidance positively affected students' approaches to learning.
Sources of data	Observational notes, video records, interviews and written responses	Observational notes, video records, interviews and written responses	Observational notes, video records, interviews and written responses

The following sections discuss and summarize the key findings reported in this study in chapters 5, 6, and 7.

8.4 Role of scaffolding (RQ1)

In the investigation of the first research question, this study conceptualised POEE as a multimodal scaffolding strategy to be used in the online environment for inquiry learning. It was found that the introduction of the *Evaluate (E) phase,* for providing synchronous feedback, to strengthen the original POE scaffolding strategy facilitated students' engagement and learning. The results contributed to delineating four key features of multimodal scaffolding. First, the *POEE pedagogical strategy* was conceptualised as an overall scaffolding framework to support students' inquiry learning in an online environment; and second, *instructional guidance;* third, *multiple external representations;* and, finally *inquiry questions* were embedded within the POEE framework to guide and regulate students' activities. These features in combination formed a framework for the design of multimodal scaffolding for use in online inquiry learning.

8.4.1 The POEE strategy provides direction for self-directed learning

The evidence discussed in chapter 5 appears to support the hypothesis that the extended version of the POE strategy can facilitate effective students' engagement with the learning activities. The underlying scaffolding tools embedded in the POEE strategy, that is, instructional guidance, multiple external representations, and inquiry questions facilitated this engagement. This conceptualisation of the scaffolding strategy was supported by the notion of structural and interactional scaffolding proposed by Hammond et al. (2005). The following *figure 8-1* illustrates how the multimodal scaffolding supported the students' inquiry process during their learning.

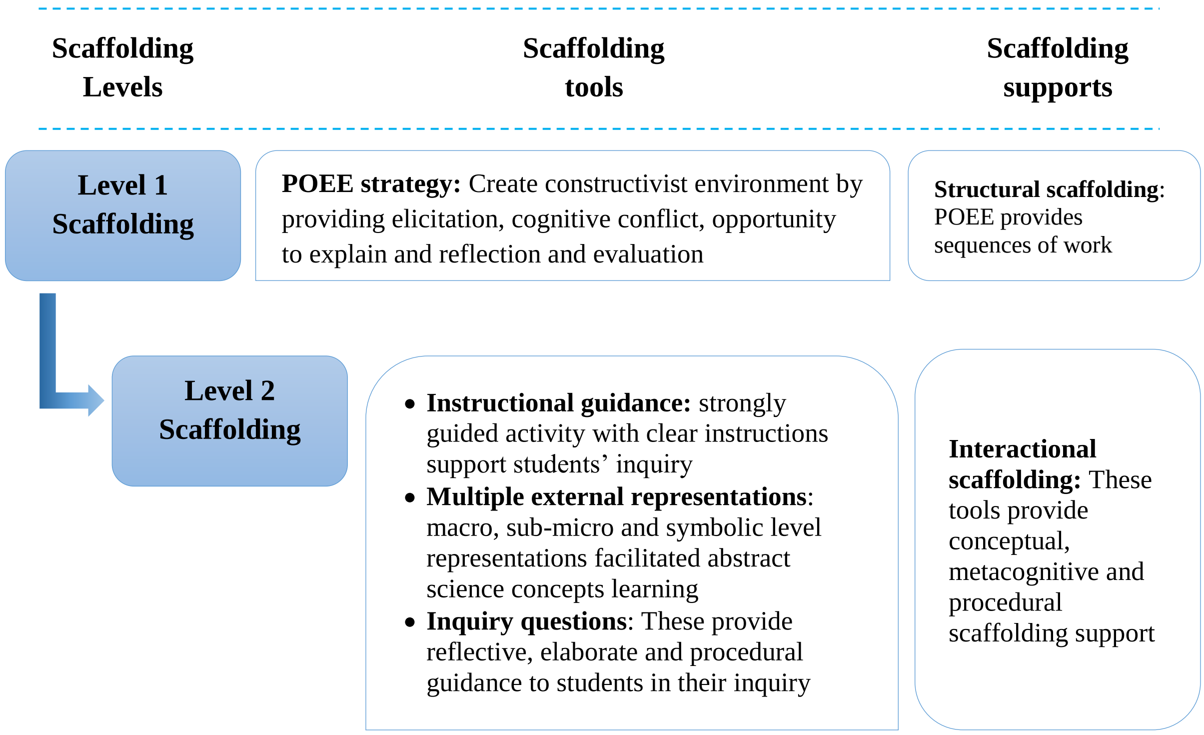


Figure 8-1: Conceptualised multimodal scaffolding support for online inquiry learning

This study found that in the online environment, the POEE scaffolding framework provided the structural scaffolding underpinning the task sequence (See Chapter 5 for detail discussion). The secondary scaffolding tools embedded in the POEE framework functioned as interactional scaffolding. These two levels of scaffolded support worked in tandem to enhance students' engagement and provided an opportunity for them to inquire into the scientific phenomena in multiple ways.

The first level POEE scaffolding strategy fulfilled the four conditions of constructivist learning environment suggested by Baviskar et al. (2009). In their study, Baviskar et al. (2009) argued that the constructivist environment needed to establish four essential criteria that enable the student to construct knowledge or build on their prior knowledge. These criteria are: a) the elicitation of a student's prior knowledge; b) provision of a context that creates cognitive dissonance in a student's mind; c) giving a student the opportunity to apply the new knowledge; and d) providing feedback and support for reflection and clarification during the learning process. These four conditions of a constructivist learning environment are realised in the actions of the students in response to the POEE scaffolding strategy implemented as part of the instructional design in this study. Examples of evidence that were elicited that support the realisation of the four criteria are provided in *table 8-2*.

Table 8-2: Example of evidence of a student behaviour in constructivist learning environment

Tools used	Example of evidence: Student's response	Researcher's Comment
	Criteria 1: Elicitation of student's prior knowledge (section 5.2.1; chapter 5)	
Cognitive conflict question, CgCQ4: On a cold day, when you grab a metal box with your bare hand it feels very cold. When you hold a second box, which is made of plastic it does not feel cold. Explain why the metal box feels colder than the plastic box.	*The metal box feels colder as heat is transferred more quickly to the hand than the plastic box* [HTSEM207]. (Written response)	The student drew on his prior knowledge which was elicited through this question. That student addressed the issue that heat transfer is faster from metal to hand in comparison to plastic. This is clear evidence that the student has prior knowledge of this phenomenon and therefore he explained it based on his prior understanding.
	Criteria 2: Create cognitive dissonance (*section 5.2.1; chapter 5*)	
	This concept is confusing a little bit. I actually did stuff like that and I just can't remember anymore, unfortunately. I don't know why, but I thought, I am kind of confused with the concept, and I am assuming that metal is a quicker conductor and it drags the heat away from your hands faster than the plastic as it's a poor conductor. [HTSEM207] (Quote from interview)	When the student failed to produce a satisfactory answer, it created cognitive dissonance and eventually, the student realised the gap between his prior knowledge and the problem being presented. The cognitive dissonance created intrinsic motivation and led him to explore the concepts.
Concept check question,	**Criteria 3:** Applying the new knowledge (*section 5.4.1; chapter 5*)	
CnCQ8: In a popular lecture demonstration, a rod that is half wood and half metal is wrapped tightly with a sheet of paper. If	*The half of the rod that has the burnt paper is the wood as it is a poor conductor of thermal energy. Metal, on the other*	After exploring and experiencing the simulation model, the student was asked to explain the problem in a new situation. The student

held over a flame, the paper on one-half of the rod burns while the paper on the other half is unaffected. Which half of the rod has the burnt paper? Explain with reasoning. (CnCQ8 is a follow-up question to the previous CgCQ4 to understand how students apply their knowledge in a different situation.)	*hand, is, therefore, heat is transferred quickly from the flame to the metal rod, causing the paper to catch on fire. [HTSEM207*]. (Written response)	tried to explain and apply his understanding to address the given problem.
Synchronous feedback on	**Criteria 4:** *Support reflection and evaluation (section 5.5; chapter 5)*	
CnCQ8: Metal is a good thermal conductor. The paper loses its heat immediately to the metal, so it wasn't affected by the flame. The metal conducts the heat from the flames obtained by the paper. In wood, the paper will burn because wood is a poor conductor of heat.	*I didn't realize that, and I haven't ever really thought about that. Once I read the explanation (feedback), I was clear. I kind of understand the concept from the reading.* [HTSEM207]. (Quote from interview)	Once the student completed the written explanation, he received immediate feedback on the concept which helped him to reflect on his understanding. It gave him the opportunity to clarify and evaluate his current understanding.

Prior research has found that giving students the opportunity to write and explain their answers by applying their understanding in a new situation introduced positive learning effects in POE settings (Kearney, 2002, 2004). Specifically, the provision of the opportunity for predicting the answers is necessary for students to gain a conceptual understanding (Crouch et al., 2004).

It was found in the current study that the provision of synchronous feedback as part of the POEE scaffolding strategy was an important element for successful outcomes in the self-directed online learning. Indeed, several findings of this study (*see section 5.5, chapter 5*) align with current thinking in published research, such as that feedback provides the evaluative or corrective information about student activity and process necessary to facilitate learning (Hattie et al., 2007; Wing, 1990); feedback helps students to evaluate their answers, facilitates competencies and understanding, and promotes motivation and confidence (Hyland, 2000); students require, however, a certain level of cognitive engagement to interpret the feedback and make the necessary accommodations to their conceptual understanding (Louwrens et al., 2015). Thus, feedback, through which students receive immediate support, is found to be a key aspect of inquiry learning in the self-directed online environment.

The second level of scaffolding embedded within the POEE strategy facilitated interactional scaffolding and positively contributed to the provision of conceptual, metacognitive and procedural scaffolding support for student engagement. It was found in this study that conceptual scaffolding assisted students in understanding the complex contextual problems by pointing to the direction of thinking and through the elicitation of their prior knowledge (*see table 5.2; chapter 5*). Metacognitive scaffolding assisted the students to achieve higher order cognition through the regulation of their thinking (*see table 5.3; chapter 5*). This metacognitive process assisted students in their planning, affording them the opportunity to evaluate their progress, and through proposing self-regulatory strategies and related monitoring processes. In contrast, procedural scaffolding was mostly found to be responsible for helping the students to understand the simulation environment, become familiar with the contents embedded within the online environment and to enhance their learning (*section 5.3.4; chapter 5*). Procedural scaffolding guided students through the process of learning by providing tutoring in system functions and features to utilize the available tools and resources, usually through the use of instructional guidance (Hannafin et al., 1999; Yu et al., 2013).

In essence, this scaffolding strategy encouraged students to consider their initial understanding and then facilitated their understanding during the process of developing concepts through observation and interaction with the simulations. As an overarching strategy, the POEE environment provides student interactivity, the opportunity to engage cognitively, and a multimedia environment, which are the key ingredients for successful learning reported by Rapp (2005). In short, the POEE strategy signifies a new development in the use of the original POE strategy to explore abstract science concepts in online settings.

8.4.2 **Self-directed learning facilitated through instructional guidance**

This study illuminated and confirmed the positive role of clear instructional guidance in online inquiry learning settings (*section 5.3.4, chapter 5*). Self-directed online learning with interactive hypermedia is considered to provide a constructivist learning environment. However, even in a strongly guided context, as observed in this study, there were 29% of cases where students embarked on self-exploratory learning without directing sufficient attention to the instructions (see *section 6.3.2, chapter 6; section 7.2.3, chapter 7*). This suggests that the path to embracing the unknown can remain open-ended even when instructional guidance is provided.

Therefore, the question raised here is how much instruction might adequately meet student requisites for guided instructions in the self-directed environment? It was found that strong guidance with detailed instructions appeared to be the most beneficial strategy for effective student learning *(section 5.3.4; chapter 5).* This finding supports an argument offered by Kirschner et al. (2006) about the implications of human cognitive architecture for constructivist instruction such as guided activities. Moreno (2004) noted that many research studies found that students learned and understood more in-depth when guided learning was provided. In the field of science education, Klahr et al. (2004) examined the impact of open ended discovery learning and guided instructions on learning to test whether students were able to transfer their learning to a new situation. They found that detailed instructions resulted in far better learning than the results derived from the discovery approach.

Guided instruction also created learning opportunities to support the process of long term transfer and problem-solving skills (Mayer, 2002).

In support of the above findings, 75% students were observed to engage less effectively in open or minimally guided activities *(section 5.3.4; chapter 5).* This indicated that open exploration did not promote engagement and learning as much as was observed for the strongly guided activities. It was also observed that students often failed to discover the underlying concepts independently when no support was provided. Even though it might be argued that more freedom is preferable as open-ended environments can privilege students with a higher level of autonomy and prior knowledge (Blikstein, 2013), the findings of this study clearly supported the provision of strong instructional scaffolding. A recent meta-analysis further supports the findings of this current study and revealed that discovery or inquiry learning without direct instructional supports is less effective (Alfieri et al., 2011; Lazonder, 2014).

In summary, in the self-directed environment, it is evident that student success in part relies on the level of instructional supports embedded in the context.

8.4.3 **MERs facilitated students' understanding of abstract science concepts**

Additional outcomes under the first research question (RQ1) revealed that multiple external representations (MERs) worked effectively to support students' development of their understanding of abstract science concepts (*section 5.3.1, chapter 5*). Learning of abstract science concepts often involves understanding scientific phenomena at the macroscopic level (the phenomena we can see, feel, and hear), symbolic (texts, formulas and equations), and sub-microscopic (existence of entities at the atomic scale, that is atoms and molecules), and the connections between them (Johnstone, 1993).

In this study, the adoption of dynamic videos and animations, and interactive simulations were found to be effective scaffolding tools to support the development of mental models of entities and processes at the sub-micro level. (*section 5.3.1; chapter 5*). During the interviews, students self-identified as requiring these resources or tools to support visualisation when describing why they had found the MER-based learning experiences helpful. For learners to be successful in developing mental models by engaging with different modalities of MERs, they must extract thematically relevant information from the MERs and incorporate it into their knowledge structures (Lowe, 2003). Students in this study reported that the simulation and video activities helped them to visualise structures, spatial arrangements and the dynamic behaviour of molecules. These visualisation skills enable students to challenge and overcome the well-known misconception that they may carry over from school. For example, the well-known misconception tested in this study was that the chemical composition of water vapor is H_2 and O_2. A recent study conducted by Lawrie et al. (2017) reinforces the notion of the persistence of this alternative conception that students suffer due to faulty learning. To minimize the effects of the pedagogic learning impediment Lawrie et al. (2017) suggest the need to challenge student thinking and shift their mental models with the support of visualization tools. The current study evidenced that students correctly addressed the misconception that the atoms in the water molecule do not separate when a phase change occurs (table 5.8, *section 5.3.1; chapter 5*). This finding suggests that the design of the instructional modules is supportive for minimizing the students' misconceptions when the MERs are well crafted within the modules.

Working on the potential for MERs to be utilized as part of the exploratory learning process, this study presented evidence from a cognitive point of view that MERs advanced students' learning capacity by facilitating their cognitive processes during learning (*section 6.2.3, section 6.4.2; chapter 6*). MERs were observed (68%) to make students' inquiry learning engaging leading to processing of the information in different cognitive ways of learning because they were embedded in this study in multiple forms. The research found that when the information was available in more than one format, learning was facilitated (Mayer, 2002; Moreno et al., 2004; Schnotz, 2005). Research also indicates that integrating multiple representations allows learners to understand complex scientific processes more deeply (Mayer, 1999). This viewpoint has been validated by other studies in which it was ascertained that exploratory tools help students understand the functions of a complex dynamic system and thus enhance their cognitive understanding (Harper et al., 2000).

However, there were instances where several students failed to capitalise on the benefits of MERs in the self-directed environment. As observed, these students were identified mostly as novice learners due to a lack of prior online experience. Research has reported that it is difficult for novices to visualize and make connections with what is occurring at the sub-microscopic level as the molecules are not visible to the naked eye and related concepts are abstract (Jones, Jordan, & Stillings, 2005). More detailed discussion related to prior online experience has been made in section 8.5 and 8.6.

In brief, this current research study confirmed that in the self-directed online environments when multiple external representations are integrated with instructional support, they can potentially facilitate students' engagement and learning.

8.4.4 **Inquiry learning is conceptualised as questions driving learning**

Question and prompts were used as part of the instructional design in this study to scaffold students' inquiry in the online self-directed environment and collected data indicated that this strategy had been successful. Research within science education has found that the type of questions posed to students, and the forms in which they are asked, can to a large extent influence the nature of students' thinking as they engage in the process of constructing scientific knowledge (Chin, 2007). It was found in this study that the questions posed played a significant role in supporting students' inquiry learning (*section 5.2.1, 5.3.2, 5.4.1, 5.4.2; chapter 5*). Based on these findings, it could be concluded that the inquiry learning was question-driven, because, a variety of inquiry questions were embedded into different tasks to support the inquiry process. These questions and prompts facilitated conceptual, metacognitive and procedural scaffolding support whilst students were investigating a scientific concept; thinking of ways to understand the concept; looking for possible reasons for the scientific phenomena; coming up with explanations, evaluating and communicating them; and revisiting the activity for revising or reconstructing their understanding if necessary.

Four types of questions were adopted for the instructional design. These were: cognitive conflict questions; concept check questions; confidence check questions; and question prompts to support students' inquiry learning. The following *table 8-3* summarises how the findings revealed the efficacy of these questions:

Table 8-3: Efficacy of inquiry questions

Question types	**Scaffolding support**	**Findings**
Cognitive conflict questions	Conceptual and metacognitive	Elicit initial ideas; awareness of self-knowledge; awareness about the limitation of the knowledge to explain the phenomena (*section 5.2.1, 5.2.2; chapter 5*)
Concept check questions	Conceptual and metacognitive	Thinking is directed to a specific concept; thinking is regulated to construct knowledge of the problem; thinking of ways to understand the concept, looking for reasons for the scientific phenomena, generating explanations, evaluating the constructed knowledge, revisiting the original answer to make a reasonable explanation (*section 5.4.1; chapter 5*)
Question prompts	Conceptual, metacognitive and procedural	Help to articulate thoughts and construct explanations; make justifications, and carry out reasoning related to problem scenario; help to reflect, and self-monitor the learning process; support students to identify and analyse the features and functions to complete a specific task; (*section 5.3.2; chapter 5*)
Confidence check questions	Metacognitive	Promote self-reflection on the explanation; encourage the articulation of thoughts and ideas; monitoring their own thinking (*section 5.4.2; chapter 5*)

A key finding in this study was the validation of using different types of inquiry questions that support students' engagement and learning through conceptual, metacognitive and procedural scaffolding supports. This form of scaffolding promoted articulation of thoughts and ideas and encouraged students to connect newly constructed knowledge with their prior understanding. In particular, the provision of conceptual scaffolding, through the use of guiding questions during learning with hypermedia, can positively influence students' learning of challenging science topics

(Moos et al., 2008). Empirical research also reveals that higher-order questions can foster the development of metacognitive knowledge (Ozgungor et al., 2004).

In summary, this study conceptualised that the use of inquiry questions resulted in positive learning effects and enhanced student inquiry learning. The use of different types of questions in each POEE task increased students' level of commitment and encouraged the formation of links between new and old concepts (Gunstone, 1995; Kearney, 2002). Therefore, it is evident that providing students with different types of questions during learning is an effective scaffolding tool, especially when they are challenged to learn abstract science concepts independently in online settings.

8.4.5 **Conclusion on RQ1**

To summarise, the findings for this research question confirmed the benefits of the framework to act as the underlying design for a multimodal scaffolding strategy for use in the online environment. This multimodal scaffolding strategy was designed and governed by POEE as the umbrella framework within which the instructional guidance, multiple external representations and inquiry questions were adopted as the underlying scaffolding support. Multimodality recognizes the variety of modes that contribute to meaning making such as students' experiences with technology where the combination of images, simulations, animations, videos and text all contribute to the meaning making process. As sophisticated technological and visual resources become more commonplace in the modern world, students are realizing the opportunities to learn and inquire in multiple ways. It is to be noted that in applying multimodal scaffolding, the focus is less on technology and more on facilitating students to develop and expand their apprehension how inquiry and understanding of the concepts might be approached in multiple ways.

8.5 **Student engagement in the self-directed online environment (RQ2)**

Previous research has established that, without teacher support in the online setting, students' motivation to engage with the learning content might begin to decline due to a lack of motivational regulation (Fryer et al., 2016). Nevertheless, this study measured substantial student engagement with the learning modules even when teacher support was absent. The key findings revealed under this research question pertain to learner autonomy, prior experience, workload, and student preferences; these considerably influence learner engagement in online contexts, factors conceptualised as intrinsic motivational elements of student engagement.

8.5.1 **Learner autonomy facilitated student engagement**

In online settings, learners typically lack direct encouragement from teachers and thus may be less self-regulated in engaging with the activities (Dembo et al., 2006). In this situation, learner autonomy plays a key role for intrinsically motivating students to engage and self-regulate their learning. This study used the POEE scaffolding strategy which offered students the opportunity to control their learning activities and thus supported their self-autonomy in the online environment. For example, in the *Predict (P)* phase, students' self-regulation was initiated by the elicitation of their initial ideas through cognitive conflict questions (*section 5.2.1, chapter 5*). These triggered their intrinsic motivation so that they began to engage with the next phases of the POEE learning activities independently. In addition, the learning modules gave students the opportunity to interact with the features, alter the parameters of simulation models, identify and view the connections between the parameters during the *Observe (O)* phase. They could also revisit a phenomenon and re-experience the simulation environment whenever they wished. Research reports this type of interactivity and control of the learning environment as important motivational factors to support the learning process (M. Yaman et al., 2008). Overall, the learning environment provided students self-autonomy and control to regulate their learning. Behavioural research suggests that a sense of autonomy, or being in control of one's choices, facilitates intrinsic motivation (Deci et al., 1987) and, in the process, contributes to the effectiveness of scaffolding (Benita et al., 2014). Therefore, a learner's degree of autonomy was found to be key to self-regulation and self-initiation of effort in the constructivist learning environment.

8.5.2 **Prior online experience dictated students' competence and self-efficacy**

This study revealed that students with prior online learning experience demonstrated a greater level (79%) of persistence with the online activities than students with less prior online experience (62%) (*section 6.2.2; chapter 6*). As observed in this study, most of the students with prior online experience quickly adapted to the learning environment and developed competency for controlling the environment thus increasing their attention to the anticipated learning. It was also found that students who did not have prior online experience could not adequately use the online environment and, consequently, failed to complete a systematic investigation (Section 6.2.2; 6.2.3 and 6.4; chapter 6). They lacked cognitive engagement and faced a two-fold challenge while interacting with the online environment. First, they needed to learn and develop the literacy and navigational competencies that would enable them to manipulate the environment. Second, they needed to focus on the original learning concepts. These behaviours are closely related to those cited in the findings of Kellman (2002) who reported two important aspects of processing information in the learning situation. One is discovery effects, which refers to finding the most relevant information while overlooking the irrelevant. The other is fluency effects, which refers to changes in the competency of extracting information rather than the discovery of related information. In line with Kellman's findings, this study found that students usually face difficulties in selecting and extracting information if they do not have prior online experience or cannot meet the literacy demands of the online environment (*section 6.4; chapter 6*).

As observed, experienced students began the initial construction of knowledge by becoming familiar with the environment and then demonstrated the ability to focus more on related and specific pieces of information in the learning modules. In their study, Moos et al. (2008) stated that, once students had built a knowledge foundation within the hypermedia environment, they could engage in meaningful exploration with an increased selection of new informational sources being accessible from the environment. This eventually leads students towards the more systematic investigation of the concepts, a finding which aligns with other research findings that prior online experiences are found to be an essential basis for student engagement in online settings. For example, Deci et al. (1991) described this ability as student competence, categorising it as an important intrinsic motivational component. This motivational competence, built on students' prior online experience, promotes their online learning self-efficacy. Online learning self-efficacy is an individual's perceptions of his or her abilities to successfully complete specific tasks required during online learning (W. A. Zimmerman et al., 2016). In the online environment, students who had prior experience of using the computer experienced higher self-efficacy (K. H. Cheng et al., 2011). These students tended to spend more time using online learning technology and were more easily engaged in their learning processes (Bates et al., 2007).

The findings also showed that prior experience governed the students' information processing skills and ability to engage in a more systematic investigation. For example, in this study, a student was required to process their learning in parallel, paying attention to the simulation models and molecular properties within the simulation models. As observed, when a novice student failed to understand the environment, it became difficult for him to learn and see the connections between the molecules and the associated concepts in the learning modules. However, some novice students overcame this limitation at the later stage of their activities once they were acquainted with the learning environment. Richardson et al. (2006) found that engagement improved as students *learned how to learn* online. The literature also suggests that as students engage with subsequent online activities, they become comfortable over time working in the online environment and the approaches to learning built into this context (Song et al., 2004). This, in turn, promotes the intrinsic interest of students to learn, the relating of new information to prior knowledge and connecting ideas across the online contents (K. Meyer, 2014).

8.5.3 **Instructional guidance affects student engagement**

The findings of this study suggest that a balance between personalized instruction and open learning seems to be preferable with appropriate scaffolding techniques being required in both formats. As reported previously, instructional guidance was one of the key elements that influenced positively students' engagement and motivation (*section 6.2.2, chapter 6; section 8.4.2, chapter 8*). Instructional guidance can help the student identify learning objectives as well as the key focus of the topic; thus, this support serves to structure the learning process and make learning objectives more transparent (M. Yaman et al., 2008). In this way, the instructional guidance appears to have contributed to increasing the learner's interest and motivation for successful engagement in the online settings.

Instructions embedded in the online module are vital components enabling students to attend to and follow the sequences of learning. The results revealed that students' engagement increased when instructions and guidance were provided (*section 6.2; chapter 6*). Instructions directed student activity and assisted them to be engaged systematically. During the open exploration, very few students demonstrated high engagement and effort due to the lack of intrinsic motivational factors such as interest in the topic, or through failure to internalize the value of the activities. The prevalence of this behaviour was explained by the student statement of preferences for different forms of instruction (*section 6.3.2; chapter 6*). It was found that many of the students wanted some guidance for undertaking the tasks. Therefore, the level of student engagement was diminished when no instruction or guidance was provided.

Though the motivational regulations were present in the guided activities, there were some obstacles that hampered students' meaningful engagement with the learning modules. One of the key findings in this regard is a student's inability to follow the instructions adequately in self-directed online settings (*section 6.3.2, chapter 6*). The results indicated that many students faced difficulties due to a lack of prior experience, complex terminology, the lexical density of the textual information and their visual disorientation in endeavouring to make sense of the environment. In addition, if the simulations appeared complex due to excessive information, students tended to misinterpret the concepts pertinent to the subject matter. This observation is supported by the study conducted by Adams, Reid, et al. (2008b) in which they suggested that the simulations must work intuitively; otherwise, a student is likely to shift the focus of attention to how to use the simulations rather than on understanding the concept pertaining to the topic. If the students do not find there is a ready interface with the simulations, they are unlikely to feel comfortable in dealing with the concepts presented; rather their attention becomes focused on the use of the simulations and, as a result, the scientific concepts will remain unexplored. These are important realizations in terms of outcomes for online learning design, that is, by providing more finely honed learning experiences for the learners, it is likely to effect an improved level of student engagement with the activity.

One of the main purposes of providing a self-directed learning environment is to promote students' development as independent learners. A dilemma, however, resides in the predicament that open exploration appears to reap potentially less productive learning outcomes. This study suggests that in most cases the absence of any scaffolding does not work except the 'case of experimenting the new ideas' (see section 7.2.3) However, over-scaffolding does not guarantee either that it gives student the best learning experiences. A possible drawback to providing explicit and strongly guided instruction is that it might reduce the level of independence of student learning. Also, students face difficulties even with explicit scaffolding due to their assumptions and incorrect inferences, lack of prior experience, complex terminology, and the lexical density of the textual information (see section 6.3.2). Therefore, to provide students the best learning experiences individualised instructions might work in online environment. Another potential solution to provide students the best learning experiences might be gradual taking out of scaffolding from the learning activities. As discussed in the above section 8.5.2, when students engage with successive activities, they become comfortable over time working in the online environment and lessen their dependence on the instructional guidance.

8.5.4 **Higher workload causes low engagement**

As discussed earlier, students' self-regulation and engagement are reliant upon intrinsic motivation. This study revealed that when the activities placed a high cognitive load on students, intrinsic motivation decreased and resulted in low student engagement. The salient example in this study is that the simulation activities attracted less student engagement compared to the video activities due to the formers' relatively higher workload in the learning process (*section 6.2.1, 6.2.3, 6.3.1 in chapter 6*). In this study, both simulations and video activities were intended to stimulate student interest by generating cognitive conflict. The POEE activity began by addressing one natural scientific phenomenon; then, a question was posed to induce an explanation of that scientific phenomenon. For example, a question was posed about why the metal box feels colder than the plastic box on a cold day (*CgCQ4*). This question appeared to elicit students' prior knowledge, pique their interest, and further arouse their intrinsic motivation to clarify their understandings which eventually facilitated their engagement (See *section 6.2.3 and 6.4.2 in chapter 6*; and *section 5.2.1 in chapter 5*).

However, many students commonly found the simulation activity much more demanding as it needed active participation and self-regulation during the interaction *(section 6.3.1; chapter 6)*. Often, they needed to invest time initially to explore the simulation environment before engaging with the original concepts. This potentially created a higher workload and thus weakened their intrinsic motivation resulting in lower engagement with the simulation activity. In contrast, students were not required to interact with the video; less information to process during learning was provided. Nor were the students required to give input, thus, by default allowing students to become more passive learners because of the lack of action required of them while they viewed the videos. This behaviour suggests that the video format provided a lower cognitive load during the learning process and so the students' intrinsic motivation was sustained throughout the video activity.

In the self-directed environment, rich information can create a heavy load on working memory if the learning process is unguided or minimal guidance is provided. In spite of the alleged benefits of unguided learning approaches to support learners to construct knowledge from learning materials, cognitive load theory advises that the opportunity for open and free exploration in an information rich and complex environment can produce a substantial memory load during the learning process, which is detrimental to students learning (Mayer, 2002; Paas et al., 2003). The issue of cognitive overload is particularly important for novice learners who lack prior knowledge and thus fail to connect and integrate the new knowledge with ill-structured existing knowledge. Therefore, to eliminate this high memory load, guided activity can play a strategic role in more effectively engaging students with the activities.

8.5.5 Students' engagement is dictated by their preferences

Students' attitudinal engagement is largely influenced by their personal preferences and interests. Research shows that, alongside intrinsic motivation, students' personal interests can determine whether and how they engage with the learning activities (Halasek et al., 2014). Earlier studies indicated that motivational and learning factors such as interest, self-efficacy, and self-regulation can affect student engagement in an online context (Bates et al., 2007; Dembo et al., 2006; Hidi, 2006). As revealed in the interview data, the students preferred instructional guidance over the open learning or minimally guided activities (*section 6.3.2; chapter 6*). This was also reflected, as observed, during their interaction with the learning modules where they demonstrated higher engagement with the guided activities. Therefore, it can be hypothesised that students' preferences for instructional guidance are related to their engagement with the learning modules. In this regard, Renninger et al. (2011) acknowledged that interest is a crucial part of increasing student engagement.

Another key example of student preference was the video activity over the simulation activity (*section 6.3.1; chapter 6*). This indicates that a video incorporating text, images, and sound, when integrated effectively, form a powerful learning tool. Indeed, videos are believed to capture a student's attention more effectively than other media (Pan et al., 2012). A video can communicate a nurturing value in instruction, and in the process, can effectively motivate learners, maintain their attention, and promote learning satisfaction (Choi et al., 2005; Koumi, 2006). Other supportive aspects of videos include eye-catching dynamic images and animations with easy and repeated access to content

(Rose, 2009). The factors associated with the videos that influence students' engagement can be categorised in the following ways:

1. Behavioural aspect: In watching the video, the student is mostly a passive learner. Unlike the context in relation to simulations, the student learns without manipulating or handling the data. Students do not need to give any physical input.
2. Attitudinal aspect: The video is less challenging yet communicates useful information more easily than the simulation does. Short focused videos are basically a powerful learning tool for the students in the self-directed environment. Unsurprisingly, students commented that the videos were enjoyable, attention-grabbing and easy to use.
3. Cognitive aspect: From the cognitive aspect, the video offers a lower load to process as students do not need to be interactive and thus kinaesthetic learning is absent. As a result, students need to focus only on visual and auditory messages, which promote students' dual coding of information (Bonk, 2011; Paivio, 1990). This improves and augments students' learning processes as they see concepts in action (Klass, 2003; Pan et al., 2012).

However, one significant determining factor influencing student engagement with the simulation activity was tactile perception. Burdea (1996) stated that, in a virtual world, the tactile experience involves a sensation applied to the skin. For example, students liked the pSim7 model because it provided the opportunity to feel the attraction of polar and nonpolar molecules and the strength between their bonds through their hands. This interesting characteristic of the simulation model creates a situational interest. Situational interest generates favorable learning motivation and increases the attention level of the students (M. Yaman et al., 2008). This was reflected in the interview where students expressed enthusiastically their preference for this tactile perception experience (*section 6.3.1, chapter 6*). Thus, it can be conceptualised that student engagement can be influenced by the nature of the learning features where, for example, tactile perception is experienced.

8.5.6 **Conclusion on RQ2**

In the online environment, student engagement can be conceptualised as the result of intrinsic and extrinsic motivational factors. The findings of this study suggest that intrinsic motivational factors were in play for student engagement in the self-directed learning environment. The literature suggests that three intrinsic motivational factors need to be satisfied, namely autonomy, competence and relatedness to intrinsically motivate oneself to initiate engagement (Deci et al., 1991). The constructivist environment used in this study essentially supports the notion of the crucial nature of these intrinsic needs of students and their need to be recognized. R. M. Ryan et al. (2000) argue that learners' autonomy and competence abilities determine the level of their engagement and facilitate their intrinsic motivation, and act as a catalyst for continued engagement with the online modules. To summarise, in the self-directed online learning context, when no extrinsic motivational factors are present, intrinsic motivational factors essentially determine student engagement. In this regard, the POEE strategy, cognitive conflict, embedded instructional guidance, multiple external representations, and question prompts used in this study maintained the motivational "temperature" across the learning modules.

8.6 Student approaches to learning in the self-directed online environment (RQ3)

In this study, student approaches to learning have been studied by observing their interaction with the learning modules and analysing their written responses. The aim was to understand how students demonstrated their learning processes while interacting with the learning modules. This study also reflected on the students' subsequent learning outcomes through analysing their written responses. Prior experience (both online and subject) once again was found to be the determining factor of student learning approaches' effectiveness, which affected their learning outcomes differentially. In addition, instructional guidance, and students' representational competence in using multiple external representations played the key role in influencing students' learning approaches.

8.6.1 Prior experiences and knowledge influence students' learning approaches

The findings from this study confirmed that students with a lack of prior online experience and subject knowledge were less able to apply deep approaches to learning in the self-directed mode (*section 7.2.1, 7.2.2; chapter 7*). In contrast, it was found that experienced students could apply their relevant prior knowledge as a starting point to better explore the simulations compared to inexperienced learners. For example, in the 'Phase Change' module, after interacting with simulation models to experience the intermolecular forces, a question was asked about which physical properties were involved in the strong intermolecular forces. In response to this question, an experienced learner used his prior knowledge and related it to the present learning experience to initiate his thinking. The student replied: "*I think a bit of both of my previous knowledge and present learning experience. I was tempted by the answer about a larger molecule or something and initially, I was thinking maybe that's it because it's bigger" [PHSEM105].* Thereafter, the student progressed towards the articulation of a more accurate mental model having realized what were the correct concepts pertaining to the problem. The progression of the student's thinking in this regard is reflected in the following comments:

> But then thinking about it I decided that well, it doesn't matter on the size of it. If you got two molecules of different sizes and both got the same charge, then it does not matter what the size is now. It's the charge that's important thing. And so that's why I thought it would be the high boiling point [PHSEM105].

This is how an example of a more experienced learner who was able to articulate the accurate mental model of a sub-micro level concept.

Cook (2006) argued that, in an information rich and complex environment, prior knowledge facilitates more expert students to categorize information as essential (intrinsic), unimportant (extraneous), or relevant (germane). The information that is essential for schema construction for a novice learner may be extraneous for an experienced learner. Experienced learners can determine more strategically which pieces of information should be processed to understand the concepts without inducing cognitive overload. Experienced students can understand the key concepts from the external representations because of their prior knowledge (Chi et al., 1982). They can discern with more discrimination the relevant information to construct an effective mental model (Schnotz et al., 1993). Therefore, differences in how learners interpreted external representations in this study were found to be largely due to the development of prior knowledge of experiences in the environment. As expected, experienced and more knowledgeable learners benefited most in developing their conceptual understanding in the self-directed online environment. Indeed, online self-directed learning is more conducive to the experienced learners progressing smoothly and successfully compared to their inexperienced peers.

Inexperienced students are more prone to cognitive overload because of their inability to categorise and select the right information. Sweller (1988) concluded that lack of prior knowledge can increase the intrinsic load of a learner. For example, in this study, during the use of the simulation model of *hSim1* in the *Heat* module, students needed to simultaneously consider the following elements: colour of the gas particles and their meanings, heating and cooling of the system and the respective temperature reading, observation of the flow of gas particle within the system, molecule movement, collisions, heat transfer process, thermal equilibrium and so forth. The possible reason could be that experienced students were able to simultaneously process this information, however for novices, the information exceeded the capacity of their working memory and thus they were constrained to work within their surface level of understanding (section 7.2.1, chapter 7). That is why inexperienced and novice students tend to accumulate fragmented and poorly defined knowledge, where information is loosely connected (diSessa, 2004). Their understanding of the external representations, as used extensively in the learning modules, is constrained to surface levels. Kozma (2003) argued that inexperienced students fail to develop an understanding of the underlying concepts because they are unable to process their mental models beyond the perceptual level.

In brief, inexperienced learners demonstrated less ability in grappling with a problem, failed to process the learning requirements in synchrony, and thus adopted a surface approach to engage cognitively in solving the science challenges. Research has consistently shown, as was also found in this study, that when students lack prior knowledge, they experience trouble attempting to engage and address the concepts even in well-structured problems (Shin et al., 2003). This issue was found to be critical in self-directed online environments, where students hold ownership of their own learning. When students have insufficient background knowledge in this environment, it may result in an inability to properly differentiate the relevant information (K. E. Chang et al., 2008), and consequently surface approaches to learning prevail.

8.6.2 **Self-directed environment is conducive to expert learners making progress**

Despite scaffolding supports and instructional guidance, many students did not perform adequately in the self-directed environment. In several cases, it was found that students used their ill-formed knowledge to address concepts that were deeply entrenched and ill-structured in memory. It was observed that, while many students completed several activities pertaining to intermolecular attractions and relating to polarity and non-polarity, some of these students reverted to their previous understandings to propose answers that were not discussed in the module. For example, a student drew upon the concept of the hydrophobic nature of oil instead of using the concept of polar-non-polar attraction to answer the question why oil did not mix with the water. Examples: '*I said that because I just learned that in biology that they are hydrophobic. So that's the thing in my head. I was thinking they are hydrophobic, so they are like move away from water" [PHSEM103].* Another student said: "*Because I was bringing information that I knew previously. But it did not work"* [PHSEM101]. Researchers have tried to find out why students maintain their existing conceptions despite instruction, and what conditions facilitate change to students' conceptions (Posner et al., 1982). Some researchers have argued that when knowledge structures are crystallized and firmly entrenched in working memory, they tend to be highly resistant to any significant change (Chan et al., 1997; Dole et al., 1998; Posner et al., 1982). Due to such resistance, a high level of cognitive effort to bring about the desired conceptual change is required.

Self-directed learning and the elements of interactivity with minimal guidance in the learning modules impose an intrinsic load on the learner. Kirschner (2002) argued that learners' working memory can be affected by the intrinsic nature of the subject topics and the way in which these are presented to learners. This potentially hinders learning, particularly for novices. Research shows that unstructured simulations do not help students to perform well compared to those where students' work was supported by a guided simulation (Rieber et al., 1995). Similarly, students who did not receive explanations of an embedded animation activity underperformed in their learning (Reid et al., 2003). In the self-directed environment, it is assumed that learning approaches rely on the ability of students to effectively adapt to the environment and manage the working load. Instructional guidance in this situation needs to facilitate their management of working memory related to the intrinsic load.

The level of expertise of a student determines how much instructional guidance is warranted for managing the task. Experienced students are able to use their prior knowledge to compensate for any lack of instructional guidance during the learning (Mayer, 2003). Because instructional guidance entails the active construction of knowledge (Cook, 2006), it was found that students with prior subject knowledge and online experience revealed deeper learning approaches in strongly guided activities. Indeed, the results of this current study confirmed that experienced learners could derive the maximum benefit in this environment regardless of the nature of instructional support they received.

8.6.3 Representational competence determines students' learning approach

The ability to demonstrate representational competence during interaction with the external representations was found to be an important skill for developing deep learning approaches (section 7.2.4; chapter 7). Many students were not able to apply these representational skills in the self-directed environment and therefore, many of the sub-micro level concepts were not realised. However, there were instances where some students had developed accurate conceptions of what was happening at the molecular level. For example, in the *hSim2* simulation model (*figure 8-2*), students understood that the red colouration (redness) represented the thermal energy of the individual atoms. Moreover, most students understood that, over time, the heat transfer process led to an equilibrium state as depicted in the graph. This redness of individual atoms, not only supported understanding of the thermal energy but also the abstract relationships between the kinetic energy, heat transfer and equilibrium process to the extent that one student tried to imagine what would happen if there were an option to replace the existing conductors with different conductors (not included in this simulation model). Example: *"It would be better may be if there is like more options for the conductor, it would just be fun to explore. Like using different elements may be. Because that's more chemistry minded."* [HTSEM103]

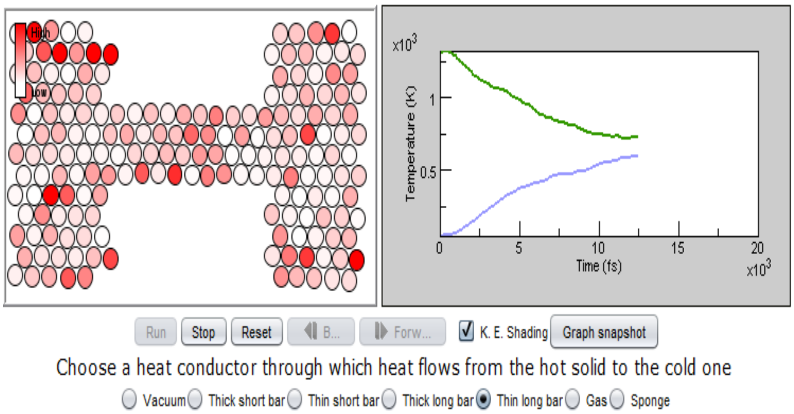


Figure 8-2: Simulation model, hSim2 from Heat module

In addition, many students successfully manipulated the axial orientation of the '*thick short*' or '*thick long*' conductor bars. Several students were able to make sense of which axis of the bar was thick and which was thin and how they varied in their surface area and impacted the heat transfer process. However, there were instances where many students failed to conceptualise the concepts due to a lack of representational competence. For example, the time differences displayed in the simulation model related to the thermal equilibrium of different conductors (*figure 8-2*). The time taken to reach thermal equilibrium was displayed on a femtosecond scale in the above simulation model. This study showed that the perception realisation and understanding of the differences between the femtosecond and real-time scales were not realized by many students since they did not develop the representational competence for understanding and translating the infinitesimal events in the simulation model.

It is clear that, for students to be able to understand the sub-micro level phenomena, they needed to grasp what was occurring through the representation of the intermolecular structures and the nature of intermolecular attractions. This suggests that the ability to succeed in the simulation environment depends on their representational competence. This argument is supported by Ardac et al. (2004), who stated that the ability to represent and translate ideas using different levels of representation affected students' learning. When students can provide an explanation that indicates an understanding of the molecular level concept and are able to create appropriate representations to externalise their thinking, they can be said to have representational competence (M. Chiu et al., 2009). Though the findings of this study reveal that some students were able to demonstrate their skills of selecting, interpreting, translating and using them to predict and address the problems at the sub-micro level, several students, however, failed to do so.

8.6.4 **Conclusion on RQ3**

Student learning approaches are greatly influenced by students' prior experience, level of instructional guidance and their representational competence in using the multiple external representations. Particularly in the self-directed online environment, more expert learners can manage their learning more efficiently than novices who are unlikely to demonstrate deep learning approaches unless substantial instructional guidance is provided. As expected, the more expert learners tended to show markedly better performances in achieving conceptual understanding when working independently in the online environment. Conversely, the surface approach to learning was evident across the learning modules when only minimal guidance was provided to novice learners.

8.7 Linking all together: Scaffolding, engagement and learning approaches

The framework of this study anticipated a relationship between scaffolded learning modules, student engagement and learning approaches within the online inquiry-based constructivist learning environment. Findings revealed that the POEE scaffolding strategy facilitated students' inquiry learning for the majority of participating students. The graphic formulated below illustrates the relationship between scaffolding, student engagement and learning approaches implemented in this study.

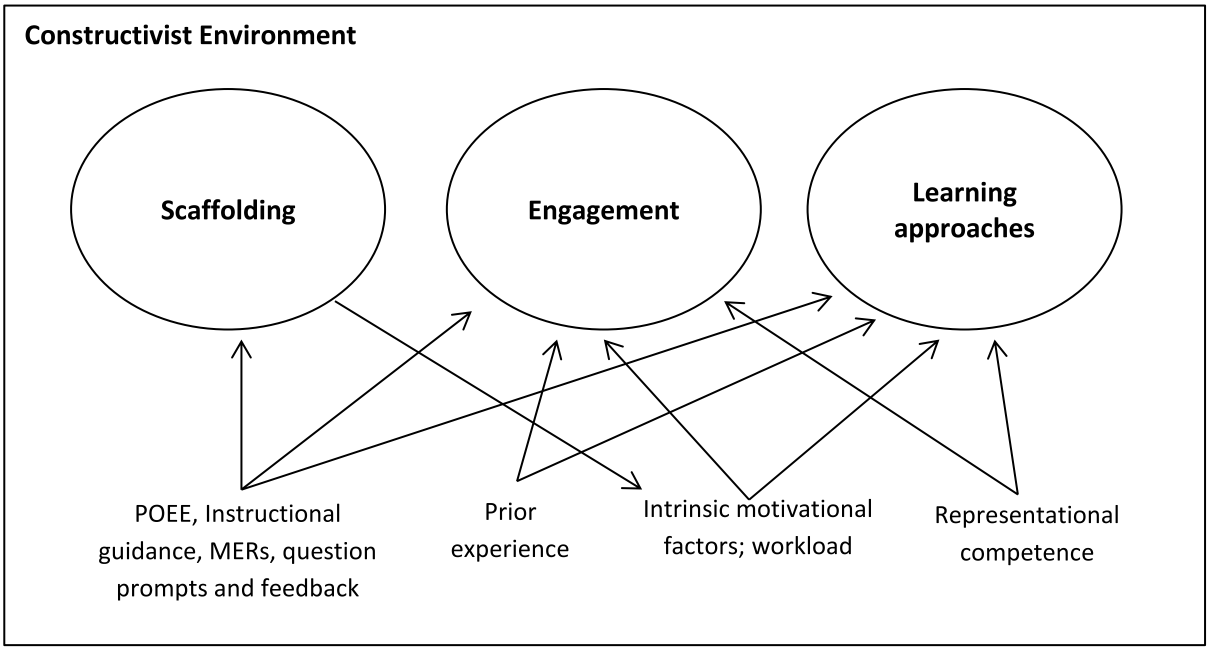


Figure 8-3: Diagrammatic relationship between scaffolding, student engagement and learning approaches

This study has provided evidence that supports the argument that the constructive environment promotes the engagement of students' intrinsic motivational factors. The use of the POEE strategy alongside instructional guidance, question prompts, and multiple external representations foster students' engagement and promote students' motivational regulation. The increased engagement was evident through students' increased attempts and persistence in the learning modules when supported with instructional guidance. Students' prior knowledge played the key role in providing a platform for increased engagement and promoting deep learning approaches resulting in conceptual understanding. In line with other findings, this study found that student deficits in prior domain-specific knowledge and experience increase difficulties for students attempting to solve even well-structured (scaffolded) problems (Shin et al., 2003).

In general, the affordances of sophisticated learning technology within the constructivist environment contributed to enhancing motivation and engagement through the promotion of mental models, and the promotion and scaffolding of higher order thinking. A parallel recent study revealed that the affordances of multimodal scaffolding helped students while they were interacting with learning content in isolation, to develop more sophisticated thinking (Boche et al., 2015).

Students' representational competence greatly influenced their engagement and learning approaches. Students with such skills can focus on the representation of sub-micro phenomena as it promotes their generation of mental models, making it easier for them to visualise and understand the concepts. McKendree et al. (2002) also argue that the use of multiple representations for a given problem or to explain a situation or phenomenon involves critical thinking. These metacognitive processes lead to deeper conceptual understanding. The results of this study support these assertions by showing that, when students use suitable multiple external representations for inquiries, their motivation for engagement and understanding of the concepts is enhanced.

8.8 Implications of this study for teaching practice

Recent technological advancement has impacted dramatically on the processes of student learning. Furthermore, contemporary research has been increasingly motivated towards determining the complex interaction between students and learning contexts (Case et al., 2009). As such, researchers are keen to know the impact of today's complex, interactive learning environment on student learning. This emphasis has resulted in changes to the design and development of technology-based applications. In this regard, the findings of this current study offer broad implications for the "marriage" of a technology enhanced, ever-changing learning environment and science education.

8.8.1 Supporting the use of the online inquiry platform for active engagement

The online environment potentially offers a more learner-centered environment, which is the central tenet of inquiry learning but is often difficult to achieve in traditional classroom settings. Working in the virtual mode helps students to participate effectively and actively in applying science, as opposed to knowing science, and exposes them to the scientific way of working, allowing them to carry out the processes of science such as stating hypotheses, engaging in experimentation and so forth (De Jong, 2006; Dewey, 1910, 1938; van Joolingen et al., 2007). Therefore, researchers have argued for the implementation of the student-oriented, open-ended inquiry learning environment (Hill et al., 2001). To this end in science education, the renewed focus on inquiry has highlighted the imperative to develop a pedagogical strategy that can successfully deploy the contents in an online setting to support students' inquiry learning processes.

The results of this study provide evidence that supports the position that online inquiry learning environments build on the constructivist notion that students' active engagement results from their participation in science activities. In undertaking the two learning modules offered in this current study, many students demonstrated systematic investigation, and persistence in effectively engaging with these learning modules. Moreover, interactive simulations and videos supported their exploration of scientific phenomena in an environment which required self-regulation. In particular, simulations which facilitated exploratory learning capabilities enabled learners to construct knowledge through interaction and visual experiences with the external representations provided. Earlier studies have also indicated the same potential for successful mediation, reporting that the interactive learning environment framed through external representations can support inquiry and provide students with more effective learning opportunities (P. S. Chen et al., 2010; Goh et al., 2013). This study highlights that novice learners require special scaffolding to tailor their engagement processes, particularly in the form of more individualised learning instructions. Novice students who encounter challenges with open or minimally guided activities especially require this explicit support as they do not have a mental launching platform in the form of sufficient prior knowledge (Kirschner et al., 2006).

To summarise, the findings suggest that the inquiry approach has implications for a practical and effective student engagement in an online environment. Therefore, this study encourages and supports the use of the online inquiry learning environment as a platform for science students.

8.8.2 **Endorsing the use of scaffolded learning modules**

The skills needed to scaffold students' problem solving for inquiry in the technology-rich environment may prove to be substantially different from those required in traditional classrooms. The implementation of apposite skills has met with challenges governed by the particular nature of context online settings. Without a structured inquiry sequence and a supportive, well-tailored pedagogy, inquiry-based learning is encumbered by these limitations militating against successful achievements being realised. In particular, to compensate for the absence of supportive knowledgeable others, successful integration of several pedagogical strategies, such as creating a student-centred environment, integrating inquiry tasks into the problem for inquiry, maintaining motivational regulation through available technologies and so forth are required. What is lacking currently, is a comprehensive yet pragmatic framework that describes when and under which conditions pedagogical strategies can be employed to facilitate students inquiry learning (Kim et al., 2011). To this end, this study endeavoured to provide students with an online inquiry platform underpinned by a constructivist pedagogy for learning science.

The results show that the POEE strategy for inquiry-based learning modules worked effectively for most of the students except for a few who were largely lacking in prior understanding and knowledge of the topics as well as experience in negotiating the online environment. In this study, well-designed educational technology tools such as PhET and MW simulations models, alongside other multiple external representations such as videos, animations and images were used to facilitate students' development of correct mental models for targeted concepts. Studies have found that multi-representations can lead to better understanding of a phenomenon (Tabak, 2004). In particular, students' arguments are more scientific and logical when they investigate using interactive simulations (K. E. Chang et al., 2008). These help students to achieve higher levels of knowledge integration (Zhang et al., 2008).

This study confirmed the utility of technology-enhanced scaffolded learning modules for inquiry learning in the self-directed online environment. The findings support the constructivist perspective that knowledge is constructed by students when learning activities are provided with considerate, carefully constructed scaffolds and instructional guidance. For instance, the *Predict (P)* phase constitutes the students' prior conception stage through elicitation of their initial ideas. The further three phases of the POEE strategy were formulated to help students explore and clarify their initial ideas to develop an accurate, solid understanding, or for revising their understanding. In practice, the scaffolded activities for each step of the POEE approaches are overarched by the "umbrella" of constructivist theory; this is implemented by prompting within students' dissatisfaction with their existing knowledge and understanding, and then challenging them to explore their ideas through different instructional activities.

In summary, this study is rooted in the understanding that inquiry-based learning with scaffolded learning modules holds promise for supporting the conceptual development of students' understanding of abstract science concepts although expectations have not always been matched by achievements, an outcome that is especially true for novice learners. However, this study concludes, that despite the inherent limitations manifest in the online context, scaffolded learning modules can provide a proximal learning environment for inquiry-based online learning.

8.8.3 **Further research implications**

There are several issues relating to the design and use of the POEE scaffolding strategy used in this study that warrant further investigation. Future research in this field should seek and provide further insights into the innovative use of the POEE strategy in an online environment. As such, further exploration and justification of the POEE strategy for learning science concepts in this context is essential.

This study used sophisticated technology tools to support students' learning. These tools that were developed to induce interactions were created on the platform of a social constructivist theory of learning. Future investigations could explore possible ways for students to communicate with peers and teachers through live online blogs and forums, which could further facilitate their reflection and understanding of the concepts they investigate. Indeed, this process might help students to engage more meaningfully and deeply in the challenging *Explain (E)* phase of the POEE strategy.

This study used multiple external representations extensively to support students' inquiry. Dealing with complex learning environments with multiple external representations in the self-directed mode, might not always produce the correct, or accurate understanding. There is always a likelihood of students' generating misconceptions and misunderstanding of the complex phenomena they experience while interacting with the simulations, even after receiving instructional guidance and feedback. Future research could explore the constraints of these features in greater depth.

The impact of students' technological competencies on engagement and learning approaches could also be further addressed in future research. This study revealed that expert and novice learners' learning approaches varied with different factors becoming implicated in this difference. Generally, novice learners could not take advantage of the self-directed environment as expert learners could. An expert student was able to adapt to the complex environment with multiple external representations with comparative ease. They could develop a mental model of abstract science concept and adopt deep learning approaches. In contrast, many novice learners could not demonstrate these skills successfully in the self-directed environment. Therefore, further research is needed to investigate the factors that create the conditions, that is, the proximal learning environment, which can facilitate the formulation of novice learners' conceptual understandings.

A recent study suggested that a video screen capture, containing audio narration assisted students to focus on salient details of the simulation and facilitated their conceptual understanding of abstract chemistry concepts while studying independently (Herrington et al., 2017). Therefore, it could be valuable to embed the audio narrated screencast with the POEE scaffolded learning modules to further enhance the efficacy of this module, especially for the novice learners. This innovation could be a productive line of investigation in the future.

One general understanding derived from this study is that open or minimal guided activity was not as effective as the guided activity. In many cases, students' attempts in the open or minimal guided activities were shown to be not meaningfully connected to their conceptual development. However, there is a need for undertaking further research to investigate whether these attempts and explorations might be categorised as failures or whether they might reap some future positive effects on students learning. In this regard, Kapur's hidden efficacy of productive failure is an important concept for driving further research. It suggests that to understand a complex phenomenon, if no support or guidance is provided to students, an apparent failure could nevertheless lead to a productive outcome in the longer term, even if it appears in the short term that a failure has occurred (Kapur, 2008) Therefore, future research could beneficially investigate Kapur's hidden efficacy of students' productive failure in the self-directed online environment.

8.9 **Generalisability and limitations of this study**

A number of issues represent possible limitations for this study. First, the POEE scaffolding framework was developed from well-known pedagogical design which supports generalizability of findings. It is proposed that the POEE framework could be used as a scaffold for students' interactions when determining the quality of students' engagement in online learning modules. Since students enrolled in introductory science courses have similar prior learning experiences in most Australian universities, it is proposed that the findings could be generalised to these educational programs. However, it is recognised that restricting the study to the context of an introductory science course in a single school has resulted in a small sample size and it could be argued that this affects the generalisability of the findings. Yet, the large volume of qualitative data has led to valuable insights that can be used to inform the development of additional effective scaffolding strategies to be used in self-directed online modules that can be translated between same level programs of tertiary institutions. There are few studies that demonstrate generalisable outcomes (e.g., Karamustafaoğlu & Mamlok-Naaman, 2015; Şeşen & Mutlu, 2016) but sharing the outcomes for individual contexts will potentially inform instructional design through a combined weight of evidence. In addition, the application of this modified scaffolding strategy in the context of online self-directed environment is novel, therefore, it does need further testing to determine whether the findings found will be generalisable to different levels of science programs.

Second, the nature of sampling technique used in this study has potential to bias the results. All participants in this study did so voluntarily (through informed consent) which is a criterion of a convenience sampling. Mackey and Gass (2015) point out that the obvious disadvantage of convenience sampling is that it is likely to be biased. Therefore, the volunteers generally have more intrinsic motivation than other students. This may impact on findings, particularly with respect to levels of engagement, in this study. Farrokhi and Mahmoudi-Hamidabad (2012) also raised an issue related to sampling in regards to the presence of outliers. Outliers are cases considered as not belonging to the data (Hatch & Lazaraton, 1991). However, the presence of outliers does not impose as big a challenge for qualitative researchers as they do for quantitative researchers since these former researchers are quite often interested in exceptional cases (Farrokhi & Mahmoudi-Hamidabad, 2012).

A third limitation of this study is in attempting to differentiate students' learning approaches based solely on their performance in the learning modules. As no pre-test has been taken before the module activity, it is very difficult to know whether these students would have been able to answers the questions without completing the learning modules. Therefore, based on performances in the learning modules, inferring that students with existing prior experience demonstrated deeper approaches to learning is likely require further investigation using a pre-testing assessment to measure their ability.

Fourth, this study assumes that the use of simulations will enhance student understanding of complex scientific phenomena irrespective of student experience with the technology. Some students may lack even basic computer skills necessary for learning in a computer-mediated environment; the achievement of this core skill was not tested in this study however no instances of poor engagement with activities were observed attributable to poor technological competency. While such students may be sparse in this digital age, these students may actually experience this impediment to their learning in the context of the learning environment adopted in this study. Further, students who experience various learning difficulties may also require specialized support to assist their learning, to enable access to these environments successfully. In addition, as the study reported, there may be some students who have developed a rigid method of monitoring their own understanding of a subject, and thus may not recognise or value feedback that is delivered through the web interface (Dedic et al., 2001).

Fifth, this study does not address any questions that arise in students' mind during their interactions with the learning modules. The assumption is made that these questions will propel students to further explore and search for their answers. Inquiry learning is based on the premise that the questioning process will be undertaken co-jointly by teacher and students. However, in this study the teachers' questions were substituted by inquiry questions and prompts, embedded within the learning modules; this strategy, while justifiable, limited prompts to a specific question related to a specific concept without any follow-up questions occurring thus further allowing opportunities for follow-up exploration and consolidation of understandings. Seeking answers to posed questions, and then following up with new student-generated questions, confirming understanding through applications and discourse are invaluable processes crucial to the success of inquiry learning (Garrison, 2003).

Sixth, students' engagement with only three videos compared to eleven simulations was measured across the two learning modules. This difference might have impacted on the results, particularly as students preferred the video activities over the simulation activities and it is known that the combination of audio and visual channels enhances learning (Mayer, 2005). It might have been a superior evaluative research design to adopt an equal number of videos and simulations in the modules.

Finally, the learning modules were designed and developed solely by the researcher who does not have any professional or certified multimedia design experience. Thus, the learning modules might not have exhibited the highest professional and educational standards in terms of the design of the user interface. Such qualities may have influenced the students' levels of engagement and learning approaches reported in the study. However, the researcher sought advice from his supervisors, collaborators and peers at conferences, relating to the pedagogical designing of the modules to minimise this limitation as much as possible (Lawrie et al., 2016).

Despite these limitations, this research has potential to add to the understanding of how scaffolding strategy influence the instructional design of a self-directed online inquiry learning environment therefore may become increasingly generalizable once evidence in related studies is published. By linking pedagogical theory, constructivist environment, web-based instructional design, inquiry questions, and multiple external representations, educators may gain a better synthesis of a self-directed inquiry-based learning environment that can better facilitate student engagement and learning in online context.

8.10 **Conclusion**

This study adopts a constructivist paradigm of research with a relativist ontology and a subjectivist epistemological approach. In addition, it enlists an interpretive, naturalistic methodology to investigate how science students engage and behave in response to the scaffolded learning activities provided in the online self-directed environment. In this study, inquiry learning is supported through scaffolded learning modules embedded with multiple external representations, instructional guidance, and question prompts. Inquiry-based learning in a constructivist environment characteristically supports students to engage in conceptual understanding. If inquiry-based learning is well supported, it can prove more effective in promoting student performance than conventional instruction (Vreman-de Olde et al., 2013).

The major contribution of this study is the development of the POEE scaffolding strategy to be used in conjunction with the online settings. This strategy might, however, be also applicable in the context of any tertiary science learning. The results of this study suggest that prior experience is the key component underpinning the whole learning process while using the POEE strategy in the self-directed online context. Therefore, this study realises for designers the necessity of considering learners' prior knowledge levels as fundamental to their maximizing the potential of this online interactive context. In this direction, guidance to educational designers of interactive learning could be in the form of identifying students' different knowledge levels and then providing them with different types of interactive simulations. (Park et al., 2009)

The study also revealed that student engagement is affected by several intrinsic motivational factors such as autonomy, competence, comfort, learning preferences and so forth. This study incorporates multiple external representations at the centre of learning, alongside instructional guidance, and question prompts. The results suggest that the students' representational skills are constitutive; that conceptual understanding, prior experience, and representational competence are interconnected and are required elements to be negotiated in learning the science concepts in the online context. As such, the present study highlights the crucial realisation that the implementation of instructional guidance is contingent upon the recognition of the contribution of several important factors. The need to provide instructional guidance, particularly the need for individualised instruction for novice learners, to promote learner's understanding of the abstract science concepts is fundamental in the context of online inquiry learning.

This study, therefore, contributes to the growing body of evidence demonstrating that the strategically designed implementation of inquiry based online learning holds promise for the creation of a successful learning environment. In addition, this study also advocates the integration of a constructivist pedagogical platform with sophisticated, concomitant multiple external representations for science learning to meet the ever-changing demand for online educational reform.

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Appendix A

Information Sheet

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

School of Education

Researcher : Md Abdullah Al Mamun, PhD student, School of Education, UQ
Advisors : Dr Tony Wright, School of Education, UQ
Dr Gwen Lawrie, School of Chemistry and Molecular Biosciences, UQ

Dear 1st Year Chemistry Student,

We are conducting a research study with the goal of enhancing student conceptual understanding in chemistry using computer simulations in a learning environment. We are aiming to design and develop interactive simulation learning modules that will address key conceptions and misconceptions held by introductory science students. Students will be able to challenge and adjust their existing conceptions by engaging in these discrete active learning modules (supported by existing technologies.

We invite you to explore one of the learning modules. Your activities in the computer screens will be recorded and monitored, after which you will be asked to participate in a face-to-face interview. The questions during the interview will focus on the following areas:

- The role of computer simulations in highlighting the conceptions and misconceptions students hold
- Investigating student's learning approaches to the interactive simulation learning modules
- The effective features of the simulations, the supportive measures, and the influence on student conceptual understanding and engagement

Please read this information sheet carefully before giving your consent to participate. If you decide to participate, thank you for your contribution. This task should take about 60-70 minutes and your permission will be sought to record the computer screen activities and audiotape the interview session to enable the researchers to revisit the information to ensure accurate analysis. All information that is obtained will be strictly confidential, unidentifiable, and will only be accessed by the researchers.

Taking part in this study is voluntary and you are free to withdraw from participating at any time. Feedback regarding the major findings of the research will be mailed to you on completion of the project. If you agree to take part in the research, please complete the attached consent form, detach and return to the researchers by email or present it before participation. Your assistance is greatly appreciated.

This study has been cleared in accordance with the ethical review guidelines and processes of The University of Queensland. These guidelines are endorsed by the University's principal human ethics committee, the Human Experimentation Ethical Review Committee, and registered with the Australian Health Ethics Committee as complying with the National Statement. You are, of course, free to discuss your participation in this study with researcher (Md Abdullah Al Mamun, contactable on 0470417380). If you would like to speak to an officer of the University not involved in the study, you may contact the Ethics Officer on 3365 6502.

Yours sincerely
Md Abdullah Al Mamun, PhD Student, School of Education, UQ

Student consent form

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

School of Education

Researcher : Md Abdullah Al Mamun, PhD student, School of Education, UQ
Advisors : Dr Tony Wright, School of Education, UQ
Dr Gwen Lawrie, School of Chemistry and Molecular Biosciences, UQ

I have read the information sheet relating to this research project, and give my consent to participate in this study based on the understanding that-

1. I am aware of the general purpose, methods and demands of the study
2. My participation in this study is voluntary and I am free to withdraw from the study or refuse to take part at any time, without any negative consequences
3. My activities with the learning modules displayed in the computer screen will be monitored and recorded
4. I am aware that the conversation in which I participate will be recorded and transcribed
5. All information that I provide will be kept confidential
6. I will receive a $25 gift card

NAME: ____

SIGNATURE: __________________________________ DATE: _______________

Witnessed by: NAME: ____

SIGNATURE: __________________________________ DATE: _______________

If you would like to receive feedback of the major findings of the study please supply your address:

____

SUBURB ______________________________ STATE _________ POSTCODE _______

Or,

Email address___________________________

Thank you

Please return the form to the researcher

Ethical Clearance

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

The School of Education

CRICOS PROVIDER NUMBER 00025B

23 June 2014

Md Abdullah Al Mamun
School of Education

Email: m.mamun@uq.edu.au

S/N: 42995759

Ethical Clearance Number: 14-025

Dear Mamun,

I am pleased to advise that on the 20th of June 2014 ethical clearance was granted for your project "Students' Conceptual Understanding and Learning Approaches Using Simulations: An Investigation into the Learning Processes of First Year Science Students".

I would also like to remind you that any correspondence associated with your project (consent forms, information sheets etc.) must be printed on official UQ letterhead (available from the School of Education Front Office).

It is important that the School of Education receives for our records a final copy of all Information Letters and Consent forms.

If you have any questions regarding this matter please do not hesitate to contact me.

I wish you well with your studies.

Yours sincerely,

Michelle Weston
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(Postgraduate & Higher Degrees)

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Appendix B

<u>Example of observational note</u>

Objective	Observational focus
Scaffolding	How do the things organized and prioritized in the learning modules influence students activity? • Levels of guidance and scaffolding (predict, observe, explain and evaluate) and how these control the flow of students activity • Ability to use of multiple external representations • Responses or explanation in inquiry questions provide evidence that they think towards a particular direction • Changes in student conceptions and misconceptions displayed in their responses after and before exploration of the simulations • Use of feedback and how it influences students reflection and reaction
Engagement	• Engagement time with the learning modules • Engagement time with the texts and images • Engagement time with the simulation models and video models • How frequent students use different features of learning modules (e.g., hints, feedback, and concept check buttons) and embedded virtual apparatus • Control and manipulation of simulations and the changes in variables to explore ideas and concepts • Following instructions • Students respond the questions and complete the activity • Students effort demonstrated during the interaction
Approaches to learning	• Students clarify their answer or confusion by checking the hints and feedback • Students' reaction to complex and difficult parts of the learning module and simulations • Students' approach to use the video and simulation during the interaction • Factors they consider and demonstrated during the interaction • Evidence that support students engagement in scientific exploration • Evidence of development of conceptual understanding • Students apply prior knowledge and skills • Students' displayed deep level of understanding in written responses

Example form of analyzing students' activity from video record

Contents from learning modules	**Researcher's focus**
Texts: Learning objectives and introductory texts	• Initial reading and engagement • Reading time of learning objectives and initial texts • level of engagement demonstrated
Questions: Open response and multiple choice questions	• Time taken by the student to complete the task • Initial thought processes and understanding demonstrated • Students review the answer • Students clarify their answer or confusion by checking the hints and feedback • Analyzing student responses: concepts identified by the students, any misconceptions demonstrated, missing concepts • Overall effort/engagement level demonstrated • Approaches to learning demonstrated • Reading the feedback • Sign of any improvement of conceptual understanding and development • Student attempted to interact with the simulation during written responses • Demonstration of following the instructions and setting up the experimental situation
Videos	• Engagement time • Students' skill in running/ opening of the video in ease • Understanding the concepts of the video • Reading the texts around the video • Ability to follow the instructions • Controlling vide: pause/rewind/forward button to explore • Student complete watching the video without any trouble • Identify any actions that confirm student's deep attention or confusion, e.g., students replay/ pause for a specific moment/ concept/ to observe deeply • Overall digital literacy demonstrated
Simulations	• Engagement with the simulation • Students' ability to run/open the simulations • Understanding the concepts presented through the simulation • Reading the texts around the simulations • Ability to follow the instructions • Controlling and manipulating simulations: use of run, stop and reset buttons, heating, cooling and temperature buttons, snapshots, kinetic energy shading button etc. • Experimenting new ideas • Experiencing the extreme heating and cooling • Explaining the understanding in the snapshots • Overall effort /engagement level with the simulation models • Identify any actions that confirm student's deep attention or confusion: such as student play with a specific moment/ concept/ behavior of the molecules; students pause/forward the simulation models frame by frame to observe deeply any event. • Ability to demonstrate the digital literacy

Examples of questions asked in the interview

1. You explored the simulations for a while. Can you just tell me a little bit, about what you were thinking about while you were doing that?
2. Then you started thinking about writing something in one of the boxes. What happened about then? What made you make the decision there to start trying to write?
3. How confident you are about your answer?
4. You wrote something second time. Did you make any alteration? Why?
5. You smiled there; did you now understand why it is happening? What makes you understand this concept?
6. In the first question, after getting wrong, you get back to the simulation to check something. What concept did you really check when go back to the simulation?
7. Is there anything that creates misconceptions instead of clarifying the concepts?
8. What did you feel about different activities as you are doing that? What did you find most interesting in the learning modules?
9. Did any of the things you saw surprise you or difficult and incomprehensive?
10. What have been more useful for you in the learning modules?
11. There are different features of simulations (e.g., hints, feedback, and concept check buttons). What do you think about the usefulness of these and use these for understanding the process?
12. Sometimes you use the virtual apparatus embedded in the simulations. Tell me how you feel about these features. What is your thinking? Do you think these make the simulations interface complex/simple?
13. Do you like the controlling the simulations as you controlled in this activity? How do you compare it with other way of studying, e.g., someone will narrate the things and show it to you, instead of controlling it by yourself?
14. Do you think controlling and manipulating of simulations create more opportunity for learning or create more burdens on student's work memory?
15. Would you like to explore more open way to get the answer? Or would you like to get some hints at the half way or at the beginning to find the answer?
16. Are you confident about your autonomy during interaction in the learning modules? Are you confident in learning while you control your own learning process?
17. What do you think about the feedback?
18. You change variables at some point. What makes you to change it?
19. You did / did not check and revise your responses in the simulation module, why or why not?
20. You have start writing to answer the questions, but you left it incomplete. What makes you respond the questions incomplete?
21. You come back several times to this activity, what makes you to revisit this?
22. You have skipped this video, is there any reason for that?
23. You just explored the virtual simulation models, but out there is the actual thing around us, any thought on this model object and real object relationship?
24. Are you aware about dealing with sub-micro level particles in the simulations models? What do you think about that?
25. What factors attract you to involve deeply? Is there anything that distracts you from learning?
26. How do you feel about the complex and difficult parts of the learning modules? Do you feel any challenge, interest to solve the problem? Why or why not?
27. Do you like the integration of videos and audios within the learning modules? What effects do they have on you?
28. Do you find any difficulties following the instruction?
29. What makes you think like that, is there any trigger point in the module that change your perceptions?
30. As you mentioned that you are good at self-independent learning. I am wondering that in page two (the simulation of dipole-dipole and London dispersion force) you missed to explore the viewing modes of the simulations. What did you think at this point?

…… and so forth

Appendix C

Examples of some raw data sets

Data Set 1: Attributing time-on-task and engagement Level for the modules

Phase Change module	**High Engagement time (in Minutes)**	**Low Engagement time (in Minutes)**
pSim1: States of matter: Basics (PhET)	≥ 6 minutes	≤ 3 minutes
pSim2 : Strength of attractions in polar and non-polar liquid (MW)	≥ 2.5 minutes	≤ 1 minute
pSim3: Separated oil and water molecules	≥ 3 minutes	≤ 1.5 minutes
pSim4 : Single water molecule, ice and liquid water (JMOL View)	≥ 2 minutes	≤ 1 minute
pSim5: Hydrogen Bonds (MW)	≥ 3 minutes	≤ 1.5 minutes
pSim6: Evaporation model (MW)	≥ 3.5 minutes	≤ 2 minutes
pSim7: Strength of attractions between polar and non-polar individual molecules (MW)	≥ 2.00 minutes	≤ 1 minute
pSim8: Dipole-dipole and London-dispersion attractions	≥ 3 minutes	≤ 1.5 minutes
pVid1: Structure of solid, liquid and gaseous state (YouTube: Canadian Museum of Nature)	≥ 1.46 minutes	≤ 53 seconds
Texts and images (Overall)	≥ 6 minutes	≤ 3 minutes
Cognitive Conflict Questions (CgCQs)	≥ 7 minutes	≤ 3.5 minutes
Concept Check Questions (CnCQs)	≥ 7 minutes	≤ 3 minutes
Synchronous Feedback	≥ 4 minutes	≤ 2 minutes
Total	**≥ 50 minutes 46 seconds**	**≤ 24 minutes 53 seconds**
Heat Module	**High Engagement time (in Minutes)**	**Low Engagement time (in Minutes)**
hSim1: Mixing hot and cold chamber (MW) (Includes taking snapshots and its explanation)	≥ 6 minutes	≤ 3 minutes
hSIm2: Heat and temperature: Heat conduction (MW) (Includes taking snapshots and its explanation)	≥ 9 minutes	≤ 4 minutes 30 seconds
hSim3: Heat and temperature: Thermal expansion (Includes taking snapshots and its explanation)	≥ 5 minutes	≤ 2 minutes 30 seconds
hVid1: Misconceptions about heat and temperature (YouTube: Veritasium, Dr Derek Muller's channel)	≥ 4 minutes	≤ 2 minutes
hVid2: Conceptual physics: Ball and ring expansion demo (YouTube: Paul Hewitt demos expansion of heat)	≥ 1 minutes 7 seconds	≤ 33 seconds
Texts, MCQ and pictures (Overall)	≥ 7 minutes	≤ 3 minutes 30 seconds
Cognitive conflict questions (Overall)	≥ 7 minutes	≤ 3 minutes 30 seconds
Concept Check Questions+ Synchronous Feedback (Overall)	≥ 9 minutes	≤ 4 minutes 30 seconds
Total	**≥ 48 minutes 07 seconds**	**≤ 24 minutes 03 seconds**

Data Set 2: Students level of persistence and systematic investigation in PhET simulation

pSim1: States of Matter Basics (PhET); this is a multi-concepts simulation							
Background	**Student**	**Persistence**	**Systematic Investigation**	**Behavioural Engagement**	**Cognitive Engagement**	**Learning Approach**	**Types of guidance**
	PHSEM201	Low	1 concept	Low	Low	Surface	

With Chemistry	PHSEM202	Low	0 concept	Low	Low	Surface	Open Exploration
	PHSEM203	Low	1 Concept	Low	Low	Surface	
	PHSEM204	Low	0 concept	Low	Low	Surface	
	PHSEM205	Low	1 concept	Low	Low	Surface	
	PHSEM206	Low	0 concept	Low	Low	Surface	
	PHSEM207	High	2 concepts	High	High	Deep	
Without Chemistry Background	PHSEM101	High	2 concepts	High	High	Deep	Moderately guided
	PHSEM102	Low	1 concept	Low	Low	Surface	
	PHSEM103	High	1 concept	High	Low	Surface	
	PHSEM104	High	More than 2 concepts	High	High	Deep	
	PHSEM105	High	More than 2 concepts	High	High	Deep	
	PHSEM106	Low	1 concept	Low	Low	Surface	
With Chemistry Background	PHSEM204	High	More than 2 concepts	High	High	Deep	Strongly Guided
	PHSEM205	High	1 concept	High	Low	Surface	
	PHSEM206	Low	2 concepts	Low	High	Deep	
	PHSEM207	High	More than 2 concepts	High	High	Deep	

<u>Data Set 3: Persistence and systematic investigation in three different simulations of Heat module</u>

Instructional setup	Student	Persistence	Systematic Investigation	Behavioural Engagement	Cognitive Engagement	Learning Approaches	Background
hSIm1: Strong guidance	HTSEM101	High	More than 2 concepts	High	High	Deep	Without Chemistry
	HTSEM102	High	2 concepts	High	High	Deep	
	HTSEM103	High	More than 2 concepts	High	High	Deep	
	HTSEM104	Low	1 concept	Low	Low	Surface	
	HTSEM105	Low	0 concept	Low	Low	Surface	
	HTSEM106	Low	2 concepts	Low	High	Deep	
	HTSEM107	High	1 concept	High	Low	Surface	
	HTSEM108	High	1 concept	High	Low	Surface	
	HTSEM109	Low	1 concept	Low	Low	Surface	
	HTSEM110	Low	1 concept	Low	Low	Surface	
	HTSEM201	High	2 concept	High	High	Deep	With Chemistry
	HTSEM202	High	2 concepts	High	High	Deep	
	HTSEM203	High	1 Concept	High	Low	Surface	
	HTSEM204	High	0 Concept	High	Low	Surface	
	HTSEM205	Low	2 concepts	Low	High	Deep	
	HTSEM206	High	2 concepts	High	High	Deep	
	HTSEM207	High	2 concepts	High	High	Deep	
hSIm2: Moderate guidance	HTSEM101	High	2 concepts	High	**High**	**Deep**	Without Chemistry
	HTSEM102	Low	2 concepts	Low	**High**	**Deep**	
	HTSEM103	High	More than 2 concepts	High	**High**	**Deep**	
	HTSEM104	High	2 Concepts	High	**High**	**Deep**	
	HTSEM105	Low	1 concept	Low	**Low**	**Surface**	
	HTSEM106	High	1 concepts	High	**Low**	**Surface**	
	HTSEM107	High	1 concept	High	**Low**	**Surface**	

	HTSEM108	High	2 concepts	High	**High**	**Deep**	
	HTSEM109	High	2 concepts	High	**High**	**Deep**	
	HTSEM110	Low	1 Concept	Low	**Low**	**Surface**	
	HTSEM201	Low	1 Concept	Low	Low	**Surface**	With Chemistry
	HTSEM202	High	0 concept	Low	Low	Surface	
	HTSEM203	High	More than 2 concepts	High	High	Deep	
	HTSEM204	High	0 concept	High	Low	Surface	
	HTSEM205	High	1 concept	High	Low	Surface	
	HTSEM206	High	2 concepts	High	High	Deep	
	HTSEM207	High	More than 2 concepts	High	High	Deep	
hSim3: Minimal guidance	HTSEM101	Low	2 concepts	Low	High	Deep	Without Chemistry
	HTSEM102	Low	1 concept	Low	Low	Surface	
	HTSEM103	High	2 concepts	High	High	Deep	
	HTSEM104	Low	2 concepts	Low	High	Deep	
	HTSEM105	Low	1 concept	Low	Low	Surface	
	HTSEM106	Low	1 concept	Low	Low	Surface	
	HTSEM107	Low	0 concept	Low	Low	Surface	
	HTSEM108	High	2 concepts	High	High	Deep	
	HTSEM109	Low	1 concept	Low	Low	Surface	
	HTSEM110	Low	0 concept	Low	Low	Surface	
	HTSEM201	Low	1 Concept	Low	Low	Surface	With Chemistry
	HTSEM202	High	2 concepts	High	high	Deep	
	HTSEM203	Low	1 Concept	Low	Low	Surface	
	HTSEM204	High	1 concept	High	Low	Surface	
	HTSEM205	Low	1 concept	Low	Low	Surface	
	HTSEM206	Low	1 concept	Low	Low	Surface	
	HTSEM207	Low	1 Concept	Low	Low	Surface	